TAKEOFF AND LANDING ISSUES FOR A COMMON TACTICAL AIRCRAFT PROGRAM

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Summary. In this paper I examine the technical issues and some of the related operational issues that would be involved in developing and procuring one common tactical aircraft type, or a family of very closely related and highly common aircraft, to meet the requirements of three services: the Navy, Marine Corps, and Air Force. I see the divergences among these services on takeoff and landing performance as one of the three big obstacles to a genuine common tri-service aircraft program (the other two being the tri-service divergences on requirements for range/payload and combat performance, and the DoN/DoAF divergences on the way aircraft are developed and procured). In some ways, it seems to me, it is the least understood and appreciated obstacle.

My principal conclusions are as follows:

- There are valid and important reasons for the divergent take off and landing requirements of the three services.
- Nevertheless, it might very well be possible to satisfy all the requirements with a single basic common aircraft type.
- If a single common program could replace three separate programs, there is a potential for savings in the tens of billions of dollars.

I see at least four possible basic technical approaches to making a highly common tri-service program:

- A largely common airframe which comes in both STOVL (short takeoff and vertical landing) and CTOL (conventional takeoff and landing) versions — STOVL for the

Navy and Marines, CTOL for the Air Force. (This is essentially the path the ARPA ASTOVL program is pursuing, as I understand it.)

- A variant of the first approach in which there are one STOVL and *two* CTOL versions: one with strength and provision for carrier operation, and one without. This would essentially combine the ARPA approach with the sort of structural modularity demonstrated by the French *Rafale.*

- A moderate STOL (short takeoff and landing) aircraft with thrust reversing, which could take off and land with rolls of less than 1,000 feet. Such an aircraft could operate from the same strips the Marines now use for AV-8Bs. It could take off from a deck with a short run if the ship had a ski jump deck — or it could be catapulted with much lower acceleration (and thus lower weight penalty) than current aircraft. Similarly, it could make arrested landings with far lower decelerations than today's aircraft. And of course it could operate from Air Force fields.

- An extreme STOL aircraft without thrust reversing, again able to take off and land with rolls of less then 1,000 feet. This aircraft would need still less acceleration and deceleration for catapulting and arresting — and in a pinch could fly off even a flat deck with no help at all.

I am reasonably certain it is possible to build a high-performance strike fighter in any of these configurations. I am not at all certain about the costs or the performance penalties — and I do not think it is possible to be very certain without serious investigation. I know from long experience in such matters that some people will declare one or another approach is the only sensible one, others will say all are impossible — and the only way to really find out is through a lot of concerted engineering effort.

Divergent Needs for Takeoff and Landing Performance. The three services see their needs roughly as follows, so far as I can tell:

- ***Navy.*** Of course the Navy needs aircraft which can operate from ship, including at very minimum its existing carriers. More subtly, the aircraft needs to fit in well with the overall operation of the carrier, and do nothing to degrade sortie rates. The Navy might be willing to contemplate some modifications to the carriers, but not such as would make them incompatible with existing aircraft.

- ***Marine Corps.*** My understanding is that the Marines are reasonably satisfied with the takeoff and landing performance of the AV-8B Harrier and want a replacement which replicates it. For the record, the AV-8B normally operates in a short takeoff mode, with a roll of about 900 to 1,000 feet when heavily loaded for combat. (It can take off vertically only with partial fuel and no ordnance.) On return from its mission it can recover either vertically or in a very short landing mode, with the choice being largely dictated by operational convenience.

- *Air Force.* Air Force requirements generally are for aircraft which can operate from normal civil or military airfields. Almost all commercial airfields have at least one hard-surfaced runway over 4,000 feet in length (which may, however, be gravel-surfaced in Arctic regions), and most nowadays have at least an 8,000 foot strip. But the Air Force must reckon on the possibility of having to operate from bases under attack by TacAir or missiles, which may damage runways. For this reason, an ability to operate from a short undamaged section of a longer runway is desirable. Also, the aircraft may need to land and take off from strips which have been repaired rather roughly, putting extra stress on landing gear and aircraft structure. Beyond this, the Air Force is very reluctant to pay a penalty in mission performance in order to secure better field performance.

From this it would seem that the three services have three totally separate requirements which must result in at least two and quite possibly three entirely different aircraft. Why not? Are the advantages of commonality really so overwhelming?

Commonality's Advantages. One answer to the question is that Congress may be determined to force commonality. Beyond this, however, simple calculations suggest that replacing three divergent programs with one common one might result in acquisition cost savings of as much as 25% to 30% — $30 billion to $40 billion (FY 1996 dollars) in typical cases. But these calculations also show how many factors could diminish these savings, or even wash them out altogether.

Is there any way to meet all the needs with one program? One sensible and economic program?

ARPA ASTOVL. ARPA is pursuing one solution which seems to have some promise. Their ASTOVL (advanced short takeoff and vertical landing) strike fighter demonstrator project has what is called a lift-cruise configuration in which the nozzle of the engine is tilted down about 90° for vertical flight, with balance provided by a lift fan buried in the forward fuselage, engaged only for vertical flight, driven by a shaft from the engine or by exhaust gas ducted from it. This is a fairly minor variation on the Harrier configuration, using proven technology on the whole, and the risk involved is not unreasonable, at least by ARPA standards. For its performance advances over the Harrier it depends primarily on the aircraft designer's trusted ally: better engine technology. If it works, the resulting aircraft should be able to operate from Marine STOVL strips, big-deck amphibs and carriers.

One variant of this would be to make two versions of the aircraft: a STOVL version as described and a CTOL (conventional takeoff and landing) version in which the lift fan and its drive are omitted and replaced with fuel or payload. I have not had an opportunity to review this program, but I see a reasonable chance that such a scheme could be made to work in the sense that it might be possible to produce a good STOVL aircraft and a good CTOL aircraft which have high commonality and (very important on Capitol Hill) look a lot alike. The STOVL version could serve for the Marines and Navy, and the CTOL version could serve for the Air Force.

But there are some important caveats. It must be understood that ARPA is not and never has been in the business of meeting specific military needs — they are in the business of picking the low-hanging technological fruit of the moment and seeing what use they might be to the military. There is nothing at all wrong with this — unless of course you happen to have a specific need to be met. There are two consequences of the ARPA approach in this case:

- The ASTOVL demo aircraft is being designed to maximize its potential to combine successful ASTOVL operation with "interesting" mission performance using available technology. This will mean that its balance of mission characteristics will be different from that of a CTOL aircraft (of either the carrier-based or land-based flavor), and may or may not be what any particular service feels it wants or needs. In particular, from what I can see, the Navy does not feel that an aircraft derived from this program is likely to be able to meet its needs.

- ARPA wants to demonstrate STOVL: it is not looking for other ways of making a tri-service aircraft and will not go out of its way to try other possibilities in order to reduce the overall program risk.

Thus, as I see it, anyone who really wants to know whether there is a possibility of meeting all three services' needs with one program has an obligation to consider not only the ARPA ASTOVL demo program but other options as well.

Obstacles to Tri-Service Commonality. What are the obstacles to building a single aircraft which will satisfy the takeoff and landing needs of the three services? After all, not so very long ago they all were reasonably happy to be flying F-4 Phantom IIs. And some argue that the Marines never had a requirement for a VSTOL attack aircraft until the British thoughtfully developed the Harrier for them, and so can not expect to continue to have it filled unless someone else proves similarly generous. Why not simply build an aircraft which will operate from carriers and expeditionary airfields and decree that all services will use it, as SECDEF McNamara did with the F-4?

It may well come to that, of course, but it should not be thought that the objections to such a course are trivial:

- ***Marines and VSTOL.*** In addition to being able to base VSTOL aircraft closer to the scene of the ground combat, Marine expeditionary forces benefit because VSTOL aircraft can operate from big-deck amphibs, allowing Marine air to provide support even before there is an opportunity to base it ashore. It is also conceivable that VSTOL aircraft could go ashore before an airfield might be seized or an expeditionary airfield might be set up.

- ***Air Force and Weight Penalties.*** Everyone knows that the Air Force is put off by the weight penalties of carrier aircraft, but many are inclined to pooh-pooh this as a marginal matter. It isn't. The problem is that a carrier's catapulting and arresting put stresses on the aircraft's structure far in excess of those for normal CTOL operation.

To accommodate these stresses, the structure must be made stronger, resulting in a weight penalty. Wing folding and other special equipment as well as special corrosion control also add to the weight penalty. It is difficult to pin down the exact value of this penalty, but experienced aircraft designers believe it is commonly of the order of 10% of the empty weight. (And as we shall see, there is some evidence for this.)

The effects of this penalty (as well as its magnitude) will vary from design to design and from scenario to scenario, but for a strike fighter it will typically be necessary to add 20% to the gross weight in order to recover what was lost in adding the capability to operate from carriers! All else being equal, this will add 20% or so to the acquisition cost, and somewhat less to the O&S (operations and support) costs. In all, we are probably talking something on the order of a 15% increment in LCC (life-cycle costs), or about 15% fewer aircraft for the same budget. (Of course there is a savings to the Air Force in acquisition costs per unit from sharing development and producing in larger quantities, but in many cases this will not amount to as much as 15% of LCC.)

Why Are the Penalties of Carrier Operation so High? Some critics complain that the penalties of carrier basing are inflated by Navy intransigence on technical requirements. It is sometimes claimed in support of this proposition that other navies have lower standards of carrier compatibility than ours — certainly some put up with carrier aircraft and operating conditions the USN wouldn't touch with a barge pole. But they also do not have the capability to launch heavy strikes in quick succession. It is clear that many of the USN standards are directly related to needs for short launch and recovery intervals and high boarding rates to support high-intensity strike operations. Like all engineering standards, they should be subjected to continuing searching review, but I am inclined to doubt that there is a great deal of room for relaxation.

That is not to say that the weight and performance *penalties* of carrier operation could not be reduced. At the dawn of carrier aviation, the penalties were negligible, as comparisons of land-based and carrier-based aircraft of the period show. The reason was very simple: takeoff and landing speeds were so low that any aircraft could take off from and land on the restricted space of a carrier deck with only a minimum of help, given a reasonable wind over the deck. But typical tactical aircraft stalling speeds have risen by a factor of about three in the intervening 70 years, so today's aircraft require a lot of help in the form of catapults to accelerate them to flying speed in 304 feet and arresting gear to decelerate them to rest in 350 feet. Since the loads on the aircraft are proportional to the acceleration and the acceleration is proportional to the square of speed, this implies a huge increase in the loads imposed by carrier launch and recovery. In fact, for typical modern carrier aircraft the average load applied to the nose gear by the catapult is more than 2½ times the weight of the aircraft, and that applied to the arresting hook is more than 1½ times the weight — and the peak loads (which really drive the structural requirements) can climb substantially higher still.

The penalties then can be reduced by reducing the stalling speed of tactical aircraft: reducing the stalling speed by 30% will (everything equal) cut the launch and recovery loads by 50%. This in turn would make possible a reduction in the weight penalties of carrier operation and, hence, in the performance penalties.

But how to do this?

Can Stalling Speeds be Reduced? The obvious answer to the question is: "Of course — if we're willing to pay the price." Recall that

$$Lift = \frac{Air\ density}{2} \times Lift\ coefficient \times Wing\ area \times Speed^2$$

(Here the *lift coefficient* is a non-dimensional quantity which expresses the aircraft's effectiveness at converting forward motion into lift and it is assumed that some consistent set of units is used for the other quantities.) For the cases we are concerned with, we can assume, at least approximately, that

$$Lift = Weight$$

so

$$\frac{Air\ density}{2} \times \frac{Lift\ coefficient}{Wing\ loading} \times Speed^2 = 1$$

where the *wing loading* is the aircraft weight per unit area of wing. Obviously, this implies that as aircraft speed varies at constant air density, the quantity *lift coefficient / wing loading* must vary inversely as the square of speed.

Early fighters achieved high lift for both extreme maneuverability and short takeoffs and landings by combining very low wing loadings (near 10 lb/ft^2 at maximum gross weight) with relatively low maximum lift coefficients (typically about 1.3). While the designer of a modern jet fighter may struggle to reduce wing loading for combat maneuverability, wing loadings at maximum gross weight of much less than about 100 lb/ft^2 are simply not in the cards for aircraft which have to cruise with reasonable efficiency near Mach 0.8. Thus low stalling speed can be achieved only with high lift coefficients.

Figures 1 through 3 show the effects of varying maximum lift coefficient on the takeoff and landing performance of a hypothetical family of strike fighter designs. These aircraft are assumed to have about the lowest wing loadings that are consistent with good range/payload performance (100 lb/ft^2 at takeoff and 65 lb/ft^2 at landing), combined with a moderately ambitious takeoff thrust/weight ratio of 0.75 (reflecting an assumption of advanced engine technology to reduce the penalties of high thrust in weight and fuel consumption). On landing without arresting, it assumed that an automatic system applies the brakes within half a second of touchdown, rather than the two or three seconds usually allowed in landing calculations.

A maximum lift coefficient of about 2.0 is pretty near the limit of what is possible with mechanical high-lift devices on fighter-type wings: more requires something tricky, heavy and expensive like variable sweep or blown flaps and slats. Even with these expedients, no modern fighter achieves a maximum lift coefficient much over 2.5.

But let us imagine that a maximum lift coefficient of 4.0 could somehow be achieved with an aircraft of the characteristics of Figures 1 through 3. As can be seen from Figure 2, this would result in a zero-wind landing run of less than 1,000 feet, with a takeoff run in the same circumstances of about 700 feet.That is, such an aircraft could takeoff and land in the distance a Harrier needs to take off.

It would not really have the performance to take off from a conventional carrier deck without a catapult, barring an unrealistically long deck run or a high wind over the deck. But as Figure 3 shows, the acceleration imparted to the aircraft in catapulting and arresting would fall to the vicinity of half a *g* — low enough to all but eliminate the associated weight penalties.

Is it possible to raise maximum lift coefficients to this level? It has not been done in fighter-type aircraft and it certainly would present great problems, but it is not inconceivable. Aircraft with high aspect ratios (*e.g.*, transports) can achieve maximum lift coefficients as great as eight or so by aggressive blowing schemes, involving directing large amounts of jet engine exhaust over and through special flap systems. It is likely that such schemes could yield a maximum lift coefficient as great as four in a fighter, with its low aspect ratio. The question is whether any way could be found to house all the necessary apparatus within a fighter's thin wings, and how much it would all weigh. To the best of my knowledge, it has never been seriously attempted — but schemes for doing so do suggest themselves. I am going to talk more about such an aircraft later on and will call it the ESTOL — "E" for "extra". Of course, there are various combinations of wing loading, thrust/weight and maximum lift coefficient which can provide the capability to land and take off with rolls of no more than 1,000 feet (without thrust reversing on landing): all these qualify as ESTOL in the terminology I will use.

It is also of interest to consider another possibility: a maximum lift coefficient of about 2.75 combined with a thrust reverser. The Swedes have used thrust reversers (automatically actuated on touchdown) in fighters, and the USAF has considered them very seriously. As can be seen from Figure 2, an aircraft with these characteristics could both take off and land with rolls of no more than 1,000 feet in each case. This requires only a very minimally effective thrust reverser — one capable of producing a net reversing thrust of only about 13% of maximum engine static thrust, for a reversing thrust/weight ratio on landing of approximately 0.15. For convenience I will refer to an aircraft able to land and take off with rolls of no more than 1,000 feet with thrust reversing as an MSTOL/R — "M" for "moderate"; "R" for "reverser".

An MSTOL/R would also involve engineering challenges, although possibly not as great as those of the ESTOL. A lift coefficient of 2.75 could probably be obtained either with a variable sweep wing with sophisticated leading and trailing edge flap systems or else with blown flaps of a somewhat less extreme nature than envisioned for the ESTOL. The necessary reverse thrust could be obtained with simple reversers, operating at intermediate or partial thrust to reduce the thermal and mechanical loads on them. As Figure 3 shows, catapult and arresting accelerations would be roughly 1 *g* — a considerable reduction from conventional aircraft. I am assuming here that thrust reversing could not be used in deck landing, although this possibility deserves some study.

Ski Jump Launch. There is another option for launch from a deck (or on land): a ski jump. It may seem like a digression to talk about ski jumps at this point, but it ties in with the question of whether a true tri-service strike fighter might be possible.

In a ski jump takeoff, the aircraft begins its takeoff run on the level and accelerates to a speed well below flying speed before it starts up the ramp of the ski jump. While ascending the ramp (typically set for an exit angle of 6° to 12° above horizontal), some of the aircraft's forward velocity gets converted into vertical velocity or initial rate of climb. The optimal airspeed at the end of the ramp depends on aircraft characteristics and ramp angle, but for high performance aircraft it can be as little as half the normal takeoff speed. Thus as the aircraft leaves the ramp it lacks full flying speed and begins to sink. But it takes some time for this downward acceleration to use up the initial rate of climb, and during this time the aircraft continues to accelerate forward. By the time the rate of climb has fallen to zero the aircraft is considerably higher than the end of the ramp and has reached full flying speed.

Ski jump takeoffs are usually associated with the Harrier, which derives additional benefit in a ski jump takeoff from its ability to deflect thrust downward. But the principles are no different from those involved with any other high-performance aircraft. As is well known, the now-defunct Soviet Navy built several aircraft carriers of basically conventional design, but substituting ski jump ramps for catapults. The Soviets apparently intended to operate high-performance interceptors from these ships, developing a version of the Su-27 FLANKER for the purpose. The fate of these ships is uncertain, but I am not aware of any problems with the ski jump launch.

The U.S. Navy built a land-based test ramp at NATC Patuxent River and used it to test several high-performance aircraft with ramp exit angles of up to 9°. These tests were quite successful and revealed no significant problems. (Publication of this research may have influenced the Soviet decision to use ski jumps on their ships.) Under conditions roughly equivalent to those envisioned in Figures 1 through 3, these tests showed that reductions in takeoff run of 60% or more could be achieved. As can be seen from Figure 2, this means that high-performance aircraft could take off with a ski jump in little or no more distance than is needed for catapult launch.

Some lower-thrust current carrier-based aircraft, however, might not be capable of ski-jump launch within the few hundred feet of deck roll which can be achieved on a carrier. For this reason, if ski-jumps were to be introduced, it might have to be done in a way that would allow normal catapult launches to proceed at the same time. RADM

George Jessen, USN (Ret.) has suggested that this might be done by installing a ski-jump ramp in place of the catapults at the forward end of the angle deck, leaving in place the bow catapults. This seems like a plausible scheme (since the ramp ought to have favorable effects on bolter performance), but it has not been worked out in detail or tested.

A Tri-Service STOL Strike Fighter? I do not, as I say, know whether it would be possible to build an effective and attractive strike fighter with either ESTOL or MSTOL/R characteristics, but let us assume for the moment that it is. How would this fit in with the needs of the three services?

It seems clear that a ski jump installed at the bows of a big deck amphib would permit either type to take off without catapulting. For example, if the MSTOL/R fighter's deck run were reduced by 60% by using the ski jump, this would mean that it could take off in about 300 feet, a distance roughly equivalent to the length of current catapults.

To recover these aircraft, the big deck amphibs would have to be fitted with arresting gear. This could be a more modest affair than the arresting gear on today's carriers, since the accelerations involved for an MSTOL/R are only about half as great as those of current aircraft, and for an ESTOL only about a quarter as great. Depending on aircraft weight, it might be possible to recover them with very compact gear. Nevertheless, it is not clear whether any kind of arresting gear could be accommodated on these ships, leaving a question to be resolved about operations from them.

On land, it would seem that there is little question: either could land and take off from the same strips the Harrier takes off from today. Unless there is some other reason for pure "V" landings — or for takeoff performance better than the AV-8B delivers today — it would seem that this should meet Marine Corps needs.

In principle, either aircraft should have the potential for carrier suitability. The ESTOL would have landing and takeoff speeds not seen aboard carriers since the 1930s, and the MSTOL/R's speeds are very much like those of the 1940s. It is questionable, however, whether today's catapults and arresting gear could produce energy and acceleration levels low enough to take real advantage of the ESTOL's characteristics. It would probably prove best not to attempt to include catapult provisions in either aircraft, relying on ski jump take offs. Obviously, this would presuppose that ski jumps would be fitted to all carriers — but remember that most existing carrier aircraft (definitely including the F/A-18 and F-14) can use the ski jump as an alternate to catapult launch.

How about the Air Force? The Air Force, I imagine, would be perfectly happy to have a strike fighter that could operate comfortably out of 1,500 foot strips, *if* very little in the way of a weight or performance penalty were exacted. Whether this is possible can only be determined by serious design work.

Effects of Takeoff and Landing Schemes on Carrier Sortie Rates. Analyses conducted by investigators at NAEC Lakehurst compared the effects on sortie rates of various launch and recovery schemes. They concluded that a V/STOL airwing would be able to generate significantly more strike sorties in a day than would an airwing of otherwise comparable conventional aircraft employing catapult launch and arrested recovery. This was because the much smaller landing area for a V/STOL aircraft made it possible to recover aircraft far more rapidly. The advantage declined for longer strike radii, reflecting the decreasing frequency of landing operations for long-range operations. Further work by CNA analysts has greatly extended but generally confirmed the NAEC conclusions. As yet, these analytical predictions have not been tested in actual operation.

RADM Jessen has speculated that operations involving ski-jump launch from a ramp on the angled deck might also lend themselves to higher sortie rates by allowing a land-based "quick-turn" style of operation without the need for respotting the deck. These ideas have not been analyzed in detail, but if they worked out it seems that they should result in a sortie rate intermediate between that for conventional operation and that for STOVL operation.

The Rafale: a Case of Modularity. The French government has been developing a new supersonic light strike fighter, the Dassault *Rafale* ("squall" or "burst" (as of firing)), which, in different versions, is to serve both in a land-based role with the *Armée de l'Air* (French Air Force) and from carriers with the *Aéronavale* (French Naval Air Service). While the land and sea versions are not identical, it is officially claimed that commonality is 80% in terms of empty weight and 90% in terms of cost.

The configuration adopted for the *Rafale* is one common to a number of recent light strike fighter projects. This involves a mainplane with a delta planform (normally a somewhat modified delta) and a foreplane (or canard) mounted just ahead of and somewhat above the mainplane. The merits of this delta-canard configuration (like everything else in fighter design) are hotly debated, and I have known very capable and experienced designers on both sides. But there is no denying its popularity, at least in Europe. My own evaluation is that it is a very attractive configuration for a light strike fighter, but less so for larger aircraft.

As with any delta, this configuration tends to optimize for a rather low wing loading. The *Rafale*'s maximum lift coefficient is apparently limited to about 1.7, but even this modest value is enough on so lightly-loaded a wing to bring the stalling speed in approach configuration down to little more than 95 knots (little more than that of an A-6). Thus an approach speed of 115 knots is claimed for both the land and sea versions. This results in lower arresting loads than would be suffered by an aircraft which approached at faster speeds. In other respects this configuration is not so ideal for carrier operation, however.

The sea-based *Rafale* incorporates a complex and heavy "jump" nose gear, but even this will almost surely not get it fully to optimum angle of attack (though it is claimed to cut 9 knots from the catapult end speed requirement). To launch the *Rafale* from the rather feeble catapults of its existing carriers, the *Aéronavale* has adopted a variant of the ski jump idea in which a ramp is placed forward of the catapult. This is necessarily a rather small ramp (1.5° angle and about 30 feet long in the case of the French carriers), but it has beneficial effects on angle of attack as well as providing an initial rate of climb. The U.S. Navy work on ramps cited earlier also analyzed this scheme (which the authors described as CRAT, for "catapult/ramp assisted takeoff") and concluded that it provides substantial advantages for high-performance aircraft. In this case it is claimed the ramp cuts 20 knots from the *Rafale*'s required end speed.

There seems no reason to suppose that the fundamental choice of the *Rafale*'s configuration was influenced by considerations of carrier suitability, so the *Armée de l'Air* can not well complain that the *Aéronavale*'s needs have queered its basic qualities. Because of its relatively low approach speed, the *Rafale* may perhaps pay a slightly lower overall structural weight penalty than a hotter carrier aircraft, but this is probably not enough to make a major difference. So how do the manufacturers and defense ministry avoid howls of protest from the *Armée de l'Air* over the penalties of carrier suitability?

The secret seems to appear in the difference in empty weights of the two versions, said to be some 10.5% less for the land version. This is right in line with what many designers believe are the "normal" weight penalties of carrier-based operation — which suggests that through careful structural design, Dassault has been able to make an aircraft in which it is possible to build land and sea versions on the same production line with largely common tooling but with little or no weight penalty for the land version. While this is not as satisfying as finding a completely common solution for three different services, it is a significant technical achievement which bears on the problem.

Will Change be a Boon or a Bane? One thing to be realized is that any of the options for meeting tri-service take off and landing needs — whether STOVL/CTOL, ESTOL or MSTOL/R strike fighter — would undoubtedly manifest a different balance of characteristics than the aircraft we are all used to. Generally, requirements for new aircraft tend to be built on a basis of experience with existing aircraft, adjusted to reflect known deficiencies and hoped-for improvements. This works well when the requirements can be met with an aircraft which incorporates the same basic design choices as previous versions, with upgraded technology. But as we have already seen, extrapolation from existing land-based CTOL, sea-based CTOL or V/STOL designs will not result in an aircraft capable of meeting the takeoff and landing needs of more than one service.

Fighter designs are very tightly coupled: each aspect of the design affects all the other aspects — often in ways far from obvious at the outset, even to an experienced fighter designer. It is all but certain that a STOVL/CTOL, ESTOL or MSTOL/R strike fighter will not naturally duplicate the balance of performance characteristics in other areas which we are accustomed to with existing aircraft. Any attempt to force them to meet the "normal" balance of characteristics will probably result in very heavy, expensive and unsatisfactory aircraft — if it can be done at all. If the balance of characteristics which are natural or inherent to these aircraft are explored and examined objectively, however, it may be found that they can be equally satisfactory in a different way. Or it may not.

An analogy may help. When aeronautical engineers learned how to build strong and efficient monoplane wings, about 1930, the world's air arms were initially very skeptical about monoplane fighters. The problem was that a monoplane inevitably involved very different military characteristics, particularly in maneuverability and in takeoff and landing performance, and air officers were by no means sure they could live with them. One result was that Britain, Italy and numerous lesser states started World War II with significant fractions of their first-line fighter squadrons equipped with biplanes, with consequences easily predictable by those blessed as we are with hindsight.

(The U. S. Navy escaped this fate only by entering the war so late: when Hitler marched on Poland, all operational USN fighter squadrons were flying biplanes. By this time most fighter units of the Imperial Japanese Navy had efficient first-generation monoplane fighters which had an edge in speed and rate of climb over the best of current USN biplane fighters, despite markedly inferior engines. This early background of experience with monoplanes contributed to Japanese ability to field generally superior aircraft in the early part of the war to come.)

Of course, all the surviving air arms found that satisfactory monoplane fighters could be built — but they never were simply faster planes with all the virtues of biplanes, as most would have wished. This scenario was repeated in part a few years later when several major air arms (including all of ours) embraced jet engines with some reluctance and hesitation, although memories of the costs paid by those who had clung to biplanes did much to hasten that process.

This is not to say that STOVL/CTOL, ESTOL and/or MSTOL/R necessarily represent something as valuable as monoplane wings or jet engines. It could turn out that they are more akin to justly-forgotten innovations which failed to produce anything of lasting value, like rocket propulsion or turreted guns. It is impossible to form any sort of valid conclusion without first carefully weighing the design tradeoffs and considering how the resulting aircraft might most usefully be employed.

Note: This point paper reflects the author's personal views based on research in progress. It is not an expression of an official position of the Center for Naval Analyses. Notes describing the reasoning, data and calculations on which the assertions in which this paper are based will be supplied on request. The author may be reached at (703) 824-2793.

Fig. 1: SPEED VARIATION WITH MAXIMUM LIFT COEFFICIENT

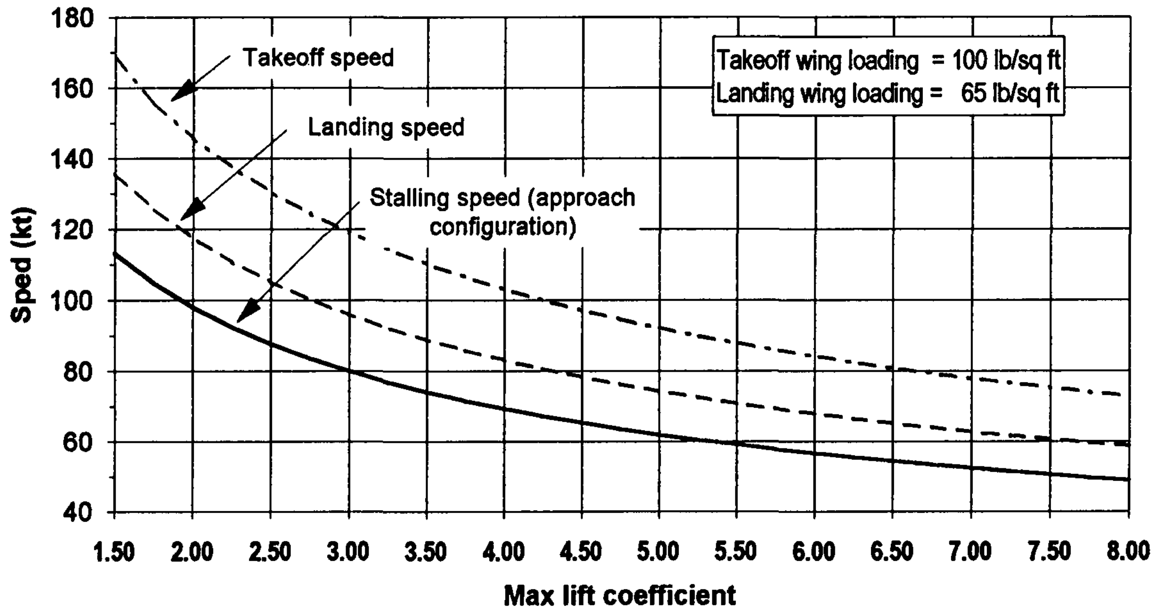

Fig. 2: VARIATION OF LANDING AND TAKEOFF RUNS WITH MAXIMUM LIFT COEFFICIENT

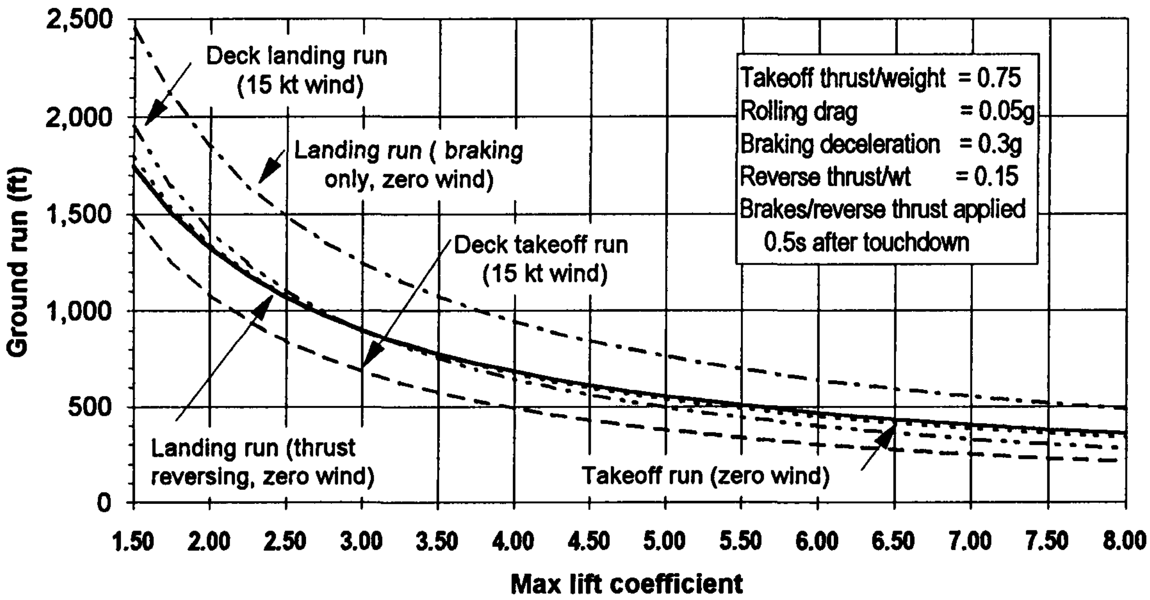

Fig. 3: VARIATION OF CATAPULT ACCELERATION AND ARRESTING DECELERATION WITH MAXIMUM LIFT COEFFICIENT