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THE IMPACT OF AVIONICS ON THE EFFECTIVENESS OF TACTICAL AIR (U)

Staff Study

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DRAFT

INTRODUCTION

In WW II it was quite clearly understood by industry and military alike that the effectiveness of aircraft in their classical missions depended on simple, mechanical aspects of the hardware involved:

1. For fighters, what counted was primarily speed and turn (although the Army Air Force generally ignored the latter) and the gun fire-power on board. Somewhat secondary was the ability to absorb punishment.

2. For attack aircraft, the primary interest was in getting close to the target with a stable platform (in order to hit) while surviving ground fire.

3. For bombers, the key characteristics were the ability to fly a stable bombing run at altitudes out of reach of effective flak, to carry to long distances a large load of bombs plus defensive weapons, and to survive AAA and fighter fire.

By the end of WW II, however, certain specialized air missions had developed for which these simple principles no longer applied - electronic equipment performance had entered the effectiveness equation:

1. Blind bombing -- the simple H2X radar coupled with the Norden mechanical analog computer opened the possibility of bombing unseen targets. This equipment degraded the already amazing inaccuracy of high altitude bombing to such an extent that it became clear that electronic equipment errors would dominate the effectiveness question.

2. Night interception -- the British-developed airborne radar intercept systems (which consisted of a radar, a scope, an operator and an intercom to the pilot), as used on the Mosquito and the Beaufighter night fighters, made possible the stalking of unaware night raiding aircraft until within visual gun-firing range. Effectiveness in this mission, given enough speed to catch the target, was almost entirely determined by how often the equipment could be coaxed to work and by the very specialized skills required of the pilot and operator team.

ALLOCATION OF RESOURCES

Today, it is generally felt that the aircraft effectiveness business has become far more dependent (in far more complicated ways) on the electronic rather than the mechanical aspects of airplanes. This may or may not be true; what is undisputable is the fact that we are spending a great deal more on avionics than on airframes. Table I, a simple classification of the FY 69 Air Force R&D budget, shows that we are spending ten times as much on avionics, space and missilery as on all aspects of airplanes, bombs, rockets and cannons.

A similar picture emerges from a classification of 10 year costs of ownership (excluding R&D) for several modern aircraft which is shown in Table II with several unfashionably simple (and presumably ineffective) aircraft for comparison.

Realistic assignment of all relevant costs to avionics is particularly important when setting aircraft requirements and making design decisions. The relevant costs are unit price, installation (wiring, air-conditioning, power, etc.), cost of operations, modifications and cost of airframe growth (engines, wing and fuel) to hold performance constant. Using the results of current ultra-high performance F-X fighter design studies, (Reference 22), modern micro-miniaturized avionics suits cost about \$800-\$1,000 per pound off-the-shelf. However, when airframe installation and growth is included, the cost shoots up to \$2,600 per pound. Adding to the avionics unit price a minimum factor of 400% for 10 year operating costs (see below) and 100% per incremental pound of airframe, it can be seen that on a modern fighter aircraft the total decision-relevant system cost of an extra pound of electronic equipment is \$7,600 or 18 times the price of gold.

Figure I gives a little more insight into the impressive dominance of avionics in cost of ownership (the data is based on extremely detailed analysis of the costs of installation, investment, spares and spares consumption rates, training and maintenance manpower but excludes airframe growth (Reference 1). It shows that, whereas airframe 10 year operating costs run about 2 times their unit flyaway cost, avionics equipment is anywhere from 4 to 20 times as expensive to operate for 10 years as it is to buy.

Table I

USAF FY 69 R&D FUNDS
( ) Indicates Percentage of Total USAF R&D

Category	Funds in Exploratory, Advanced, Eng'g and Optnl't Systems Development	
Conventional un-guided weapons (guns, bombs, rockets)	$ 24M	(1%)
Tactical aircraft and technology (w/o VSTOL)	$180M	(7%)
Electronics, missilery and space	$2043M	(82%)
TOTAL USAF R&D	$2494M	

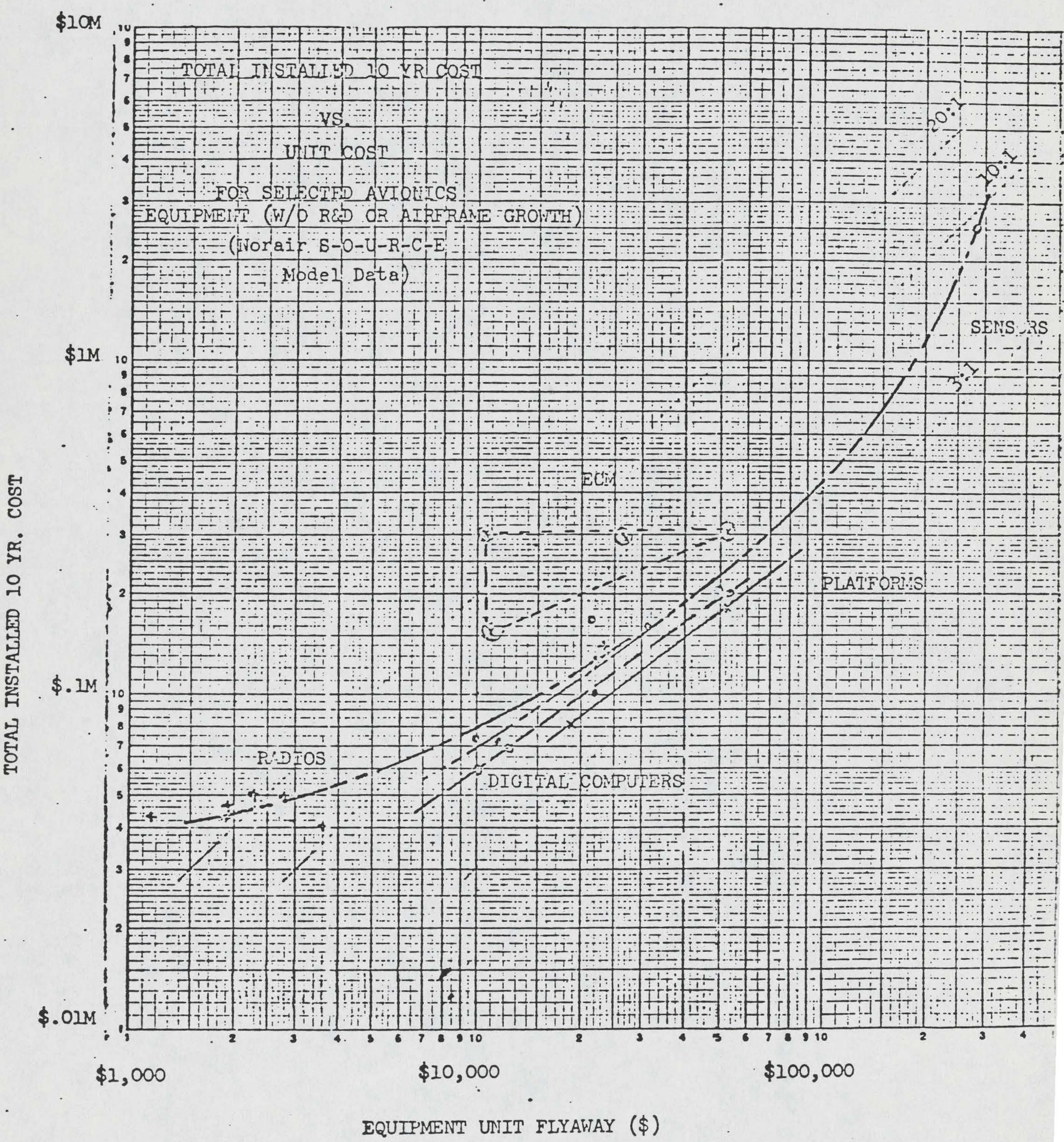
Table II

AIRCRAFT 10 YR, SYSTEMS COST IN 1968 DOLLARS
(Estimates Based on USN Program Factors)

	A-1H 1/		A-4C		F-8D		F-4B		A-6A	
	A/F	Avionics	A/F	Avionics	A/F	Avionics	A/F	Avionics	A/F	Avionics
Investment	$ .45M	$ .04M	$ .55M	$.15M	$1.1M	$ .25M	$1.6M	$ .6M	$1.6M	$1.6M
Direct Operating	1.35	.30	1.80	.80	2.25	1.1	3.3	3.2	2.8	6.7
TOTAL	$1.80M	$ .34M	$2.35M	$.95M	$3.35	$1.35	$4.9M	$3.8	$4.4M	$8.3M
% Avionics	16%		28%		29%		44%		65%	

1/ Based on Douglas estimated cost of a 1968 production run.

Fig. I


TOTAL INSTALLED 10 YR COST
VS.
UNIT COST
FOR SELECTED AVIONICS
EQUIPMENT (W/O R&D OR AIRFRAME GROWTH)
(Norair S-O-U-R-C-E
Model Data)
20:1
10:1
3:1
SENSORS
ECM
PLATFORMS
RADIOS
DIGITAL COMPUTERS
$10M
$1M
$.1M
$.01M
TOTAL INSTALLED 10 YR. COST
$1,000
$10,000
$100,000
EQUIPMENT UNIT FLYAWAY ($)

It is to be noted that the above costing gives only investment and direct identifiable operating costs, i.e., spares purchase price, maintenance manpower at field and depot level, direct base support, etc.; if "full slice" costing were used (allocating Service-wide overhead and the increasingly burdensome system modification costs), operating costs would be at least doubled relative to investment costs.

According to present plans, by the mid-70s our tactical air inventory will consist almost exclusively of highly complex, electronics-oriented aircraft (e.g., F-111 A/D, A-7 D/E, F-4 E/J and A-6); we can expect to be spending well over half of our tactical air operating budgets on the upkeep of avionics. The evidence of today's R&D resource allocations indicates that this lion's share of the operating budget will continue to increase throughout the seventies.

HOW OFTEN DO THINGS WORK?

As noted above, it became painfully apparent in WW II that electronic equipment effectiveness was sensitive to, among other factors, how often the equipment was operable. As equipment complexity escalated in the years after WW II and the problem became more acute, the field of reliability engineering blossomed. Considerable progress was achieved in this discipline in the theory of independent failures and in the empirical data base for small component failure rates. Unfortunately, the theory for correlated failures has remained computationally intractable and a comprehensive empirical data base for full sub-systems and large scale systems remains too expensive to obtain. Nevertheless, by dint of bold extrapolations, extensively documented reliability predictions are made for every major program and few systems are sold with less than .95 reliability promised.

There is little doubt that technological advances since WW II have improved individual component reliabilities by extremely large factors. Unfortunately, equipment complexity has grown at least as fast as component reliability, so that it is not necessarily true, a priori, that today's equipment works more often than yesterday's.

It is important to assess useful reliability in the context of actual squadron rather than ideal test range maintenance. The equipment manufacturer's familiar defense that better maintenance would have produced better reliability is undoubtedly justified. Nevertheless, this defense is ultimately irrelevant, since what matters is only the reliability we will be able to achieve in the next war with the actual maintenance crews we are likely to have at that time.

Now that recent testing and SEA combat experience has expanded our data base, it is of some interest to observe how often our equipment actually works. Table III gives a sample across the spectrum of system types, starting with a historical comparison.

The reader is left to decide for himself whether these equipments work often enough to be militarily useful.

EFFECTIVENESS - ANALYSIS VS RESULTS

Naturally, the heavy and increasing investments in avionics equipment over the last twenty years have been made in the expectation that we would achieve commensurate gains in combat effectiveness. To encourage this expectation, huge efforts have been expended in producing effectiveness analyses and predictions for each new development and system. The reader will be familiar no doubt with the results of these analyses: surface-to-air and air-to-air missiles rarely have P_K's of less than .9; aided visual bombing systems have CEP's no worse than 50 to 100 feet; blind bombing systems have errors of less than 10 mils or 200 feet; air-to-ground missiles generally hit within 10 feet of their aimpoint (although recently there has been a rash of 2 foot claims); night sensors detect trucks at twice the range of the unaided eye on a clear day; etc., etc. Other such analyses demonstrate that it is almost impossible to reach any target by dead reckoning; that it requires superhuman skill to shoot down another airplane without a flexible gun or at least a helmet-mounted sight; or that dive-bombing without a heads-up display containing 15 essential variables is wasted effort.

Table III

ACTUAL RELIABILITY OF SELECTED AVIONICS EQUIPMENTS

Category	Equipment	At Target Reliability	Reference
Bombing Systems	B-17 H2X	.84	2 (Combat)
	A-6A Tracking Radar only	.40	3 (Peacetime Test)
	A-6A Full radar System	.26	
Airborne Intercept Systems	F-106/MA-1 Fire Control	.37 (.04) 4/	5 (Peacetime Squadron)
Missiles	Sidewinder B	.70	6 (Combat)
	Sidewinder D	.63	6 "
	Sparrow D/E	.46 1/	6 "
	Walleye	.73 2/	7 "
	ARM(Mod 0)	.50	9 (Peacetime Test)
	Terrier		10 (Peacetime Test)
	Fire Control	.66	
	Missile	.58	
Navigation	F-4 Inertial Platform	.33 3/	11 (Peacetime Squadron)

1/ Failures counted are only obvious failure to launch or to guide.

2/ Does not include failures during pre-launch checkout or in-flight pre-attack check-out - Some sorties carried an extra Walleye for backup; the .73 quoted includes the benefits of the redundancy.

3/ Failures counted are sorties where terminal errors are outside acceptable Tech Order bounds. A larger number of sorties may have inflight errors exceeding bounds.

4/ .04 represents the probability of successfully completing a two sortie, refueling-only turnaround mission.

The following case examples will perhaps shed some light on how close to the mark these analyses have struck:

Case I -- Aided Visual Automatic Bombing Systems: Since the data base for bombing system scores consists of peacetime familiar range drops with varying percentages of bad results censored from the samples, expert pilots, and the highest quality of maintenance, one can hardly compare these CEP's with average combat results for iron sights. A fairer base of comparison would be against peacetime squadron training accuracies on familiar ranges, although one would expect automatic bombing systems to show considerable degradation (factor of approximately two) simply in the transition from the test range to the squadron. Table IV (taken from Reference 12) shows the results of the aided versus unaided delivery accuracy comparison for almost all systems tested to date (iron sight accuracies are based on the JMEM accuracy formula prediction without the inherent combat degradation factor of 2.3).

Note that not a single system tested to date has shown a consistent improvement over the iron sight; in general, they range from 20 to 300% worse.

The most promising accuracy results recorded to date are those of student pilots flying A-1's on a scoring range and achieving a 47' CEP at 40°-50°, 260 knots and 2250' release altitude (50% better than JMEM predictions for peacetime squadron accuracies).

The following conclusions can be formed:

1. No aided visual system tested to date shows any possibility of effectiveness improvements in the multiple pass close support situation where iron sight accuracy is generally equal to peacetime accuracy.

Table IV

SUMMARY OF VISUAL AIDED AUTOMATIC BOMBING SYSTEMS

System	Conditions at Release	Ratio Aided CEP to Unaided CEP	Computed CEP About Target	Equivalent Unaided Training CEP (JMEM Formula)
Mk 10/CP-741 (Radar, gyro, analog computer, fixed sight, dive toss)	30°, 3000' AGL, 450 kts 45°, 4500' AGL, 480 kts 45°, 7000' AGL, 480 kts	1.65 1.35 1.43	177' 144' 233'	107' 107' 163'

Comments: Data base is 252 drops of Mk 81, 82, 83, 89 bombs yielding ± 15 mils azimuth and ± 11 mils elevation median miss distance from target in aircraft sight-line coordinates. Test run at NOTS on a familiar range with bad sorties excluded. Dive angles of 10-50°, slant range of 12,000'-24,000'.2/ Uncorrected data used. It is not known how many sorties were excluded from the sample.

System	Conditions at Release	Ratio Aided CEP to Unaided CEP	Computed CEP About Target	Equivalent Unaided Training CEP (JMEM Formula)
LANABS (Radar, inertial, digital computer, servoed sight, dive toss)	30°, 3000' AGL, 450 kts 45°, 4500' AGL, 450 kts 45°, 7000' AGL, 480 kts	1.20 .95 .98	129' 102' 159'	107' 107' 163'

Comments: Data base is 164 drops, probably only Mk 81s and against corner reflector at NOTS. These are based on best 16 sorties out of 36 on which bombs were dropped. Based on this rather tailored sample, the median miss distances are ± 10 mils in azimuth and ± 8.5 in elevation.

NOTES: 1/ Sample included conditions not usable in combat because aircraft flies through own bomb burst.

2/ Based on VX-5 results, mil error would be worse at closer slant ranges.

Table IV (Continued)

System	Conditions at Release	Ratio Aided CEP to Unaided CEP	Computed CEP About Target	Equivalent Unaided Training CEP (JMEM Formula)
F-4D/ASQ-91	Average conditions			
(Radar, inertial,	19°, 2300' AGL, 450 kts	1.60	220'	138'
analog computer,	22°, 4000' AGL, 450 kts	1.13	205'	182
servoed sight,	32°, 2600' AGL, 460 kts	1.84	180'	98
dive toss)	32°, 3900' AGL, 460 kts	1.36	175'	129'
	32°, 5700' AGL, 460 kts	1.18	200'	170'
	43°, 3400' AGL, 480 kts 1/	2.19	190'	87'
	43°, 5000' AGL, 480 kts	1.41	175'	124'
	43°, 8000' AGL, 480 kts	1.35	245'	181

Comments: Data base is 172 sorties (with 161 maintenance actions on bombing system) of which the best 80 were scored. Radar corner reflector used in a familiar range at Nellis AFB. Only BDU-33B bombs were used.

System	Conditions at Release	Ratio Aided CEP to Unaided CEP	Computed CEP About Target	Equivalent Unaided Training CEP (JMEM Formula)
Hughes HS-100	Average conditions			
Laser Ranging System	44°, 3200' AGL, 480 kts 1/	1.27	98'	77
(laser, inertial	30°, 2050' AGL, 480 kts 1/	1.22	93'	76'
analog computer,	15°, 900' AGL, 440 kts	.89	87'	98'
servoed sight,				
dive toss)				

Comments: Data base is Eglin AFB test with 69 sorties to adjust system followed by 21 bombing sorties of which only 16 were used in accuracy computations. Both inertial and air data modes are included since no significant differences were found. Familiar ranges were used on all tests. Only M-117 bombs were dropped for this sample.

System	Conditions at Release	Ratio Aided CEP to Unaided CEP	Computed CEP About Target	Equivalent Unaided Training CEP (JMEM Formula)
A-6/P-6-visual	Average conditions			
aided boresight mode	30°, 3700' AGL, 450 kts	3.90	525'	135
(Radar, inertial,				
digital computer,				
servoed sight,				
continuous solution)				
A-6 system in degraded boresight mode	30°, 3700' AGL, 450 kts	2.67	360'	135

Comments: Data base is 344 drops of which only 164 (48%) were able to achieve a fully functioning system at release. The full system runs gave 400' CEP about the mean which was 225' from target; best results were obtained in the most degraded system mode (detuned tracking radar, no inertial, manual wind input) - 250' CEP about a mean 175' from the target. A familiar range (China Lake) with a radar corner reflector was used; presumably only one type of bomb was dropped.

2. For the one pass interdiction situation where iron sight combat degradation factors apply, there is at least a possibility that one or two of the least-tested systems might reduce bombing errors; however, far more stringent tests involving short tracking times, realistic maneuvers, uncensored samples and normal squadron maintenance would be necessary to provide acceptable evidence justifying procurement.

3. There are only two sure ways of improving unguided ordnance delivery accuracy today: a) to get closer to the target with a slower, more maneuverable and more stable platform; and b) to decrease the time of flight of the munition by such expedients as using a rifled tube launcher. The USAF SPARROWHAWK test shows that even the current 20mm aircraft cannon, with its rather poor ballistics, achieves 4-5 mils CEP in multi-pass strafing, a factor of 2-3 better than the most optimistic (untested) claims made for bombing systems.

Case II -- Blind and Night Bombing Systems: As in the case of aided visual systems, there is a long history of development dating back to WWII for these equipments. The results available for accuracy against realistic radar targets are shown in Table V. It must be noted that single CEP figures for blind bombing are spurious in the sense that CEPs for a given radar will vary by at least 5:1, depending on target difficulty. Unfortunately, despite the billions spent on radar bombing, we have no data base suitable for a scientific classification of this radar target significance effect.

An interesting insight from the peacetime tests is that results degrade a factor of 3 to 5 from radar corner reflector tests to realistic target tests. In addition, tests of the same systems in the manual timer mode show negligible differences between automatic and manual modes (generally a slight edge for manual releases). All this points to the radar's inherent lack of resolution and inability to separate targets in strong clutter as being the limiting factor in blind bombing accuracy. In other words, the complexity and expense of the automatic release mechanization of the most modern systems is simply misplaced effort until the basic radar is significantly improved (if this is indeed possible).

Until recently, the major justification for radar blind bombing has been the decrease in attrition expected when attacking fixed targets at night or in weather (ironically enough, the U.S. Air Force took the opposite side of this issue against the British night-bombing enthusiasm in WW II, arguing that the accuracy degradation suffered at night wiped out all attrition benefits). Review of the 1967 NVN combat loss

Table V

BLIND BOMBING ACCURACIES

System	Mils Accuracy Based On Altitude	CEP	Alt.	Condition	Reference
B-17 H2X	90	1,800'	20,000'	Peacetime	2
	-	22,000	20,000	Combat	2
F-105	-	2,700	1,500'	Peacetime	13
	320	1,600	5,000'	Peacetime	13
F-4	-	1,475	1,500'	Peacetime	11
	255	1,275	5,000'		11
F-111A	250	750'	3,000'	Peacetime	4
	130	650	(5,000')		4
	-	4,100	250'-1,000'	Combat (all sorties count)	
	-	1,000	250'-1,000'	Combat (40% of sorties)	
A-6A 1/	-	900'	1,000'	Combat-good targets	14
		1,500'	3,000'		
		4,800'	1,000'-3000'	Combat-difficult target	14

1/ No uncensored peacetime samples of A-6 drops against either corner reflectors or realistic radar targets has been made available since the inception of the A-6 program.

experience shows the surprising result that in the heavily defended Package VI area, bombing at night is 1.6 times more hazardous per sortie than day missions; in the rest of NVN, day losses are no more than 1.7 times as heavy as night losses.

Perhaps the most interesting aspect of these results is seen by means of a simple computation of aircraft lost per target destroyed, giving night bombing the benefit of the 1.7 advantage in loss rate. Table VI shows the computation based on the JMEM weapons effects program and actual loss rates.

The results show, that, in order to destroy a given set of targets, we lose 4 times as many aircraft by bombing at night than during the day, even if our night-time combat CEPs are as good as 750' (the peacetime test accuracy of the F-111A). In other words, it makes no sense to attack fixed targets at night.

This leaves only the interdiction of night road, rail and waterborne movements as a militarily useful objective for night bombing. In this mission, the A-26/B-57 have scored 2.0-2.5 confirmed truck kills per sortie (20 November 1967-29 February 1968) while the A-6 has achieved .6 truck claims (i.e., any secondary explosion) per sortie for the most successful squadron, VA-196 (September-November 1967 - Reference 23) with the very recent rash of successful AMTI detections (1965 score was only .07). F-4, A-4 jets have scored only .1-.2 trucks per sortie. The Gunship II program has, based on a limited and carefully planned sample of sorties in largely undefended areas, achieved a score of 2.3 kills per sortie (Reference 24); however, it is necessary to wait for normal mission schedules, defended area work and the subsidence of the passions of advocacy in order to make an objective assessment.

The largely unheralded success of the prop-driven A-26 over the Ho Chi Minh Trail is based on three simple ingredients:

1. Detection is accomplished by seating a crew member at the aft end of the open bomb bay using both a manual starlite scope ($1,200) and unaided vision. This crew member also uses an intercom to guide the pilot along the road.

Table VI

RELATIVE LOSSES PER TARGET DESTROYED FOR DAY AND NIGHT BOMBING

		Visual 270' CEP (45^o/4500' alt.)	500' CEP	750' CEP	1500' CEP
Prob of destruction w/8 M-117's	Masonry Bridge	.025	.005	.003	-
	Ammo Dump	.158	.044	.022	.005
	Barracks	.243	.061	.032	.008
Aircraft Lost/Target Destroyed 1/ on a normalized basis	Masonry Bridge	1	2.8	4.7	-
	Ammo Dump	1	2.0	4.1	18
	Barracks	1	2.3	4.3	17

1/ Using 1967 NVN (all F-4, A-4, F-105 and A-6 sorties) daytime hostile action loss rate = 1.575; nightime rate = .895 per 1000 excluding Package VI; in Package VI 7.24 per 1000 for day losses and 11.73 for night losses. Adding in the substantial non-hostile losses would cause a relative increase in night losses.

2. Detection, delivery accuracy and reattack are all significantly enhanced by the 175-200 knot cruise speed of the A-26. The excellent low altitude endurance of the prop-recip combination allows extensive coverage with up to 5 or 6 hour missions.

3. The two most effective anti-truck weapons on board are the 12 forward firing caliber .50 machine guns and the WW II M-35 incendiary cluster bomb (no longer in production).

It is extremely difficult to conceive of a sophisticated modern jet aircraft equipped with the full gamut of automated sensors, navigators and weapons release computers that would be able to match at any price the demonstrated effectiveness of the A-26 in the night truck interdiction mission. This does not imply that an even more suitable, survivable and lethal airframe than the A-26 cannot be built today.

Case III -- Surface-to-air & air-to-air missiles: It seems incredible in the light of our experience today that there was once a time when technical people believed so strongly in the invincibility of air-to-air missiles that they favored transport-type, long range missile launching aircraft as fighters. Interestingly enough, today's Phoenix Missile System (Note 1), born from the ashes of the cancelled Eagle/Missileer program, is the direct product of this concept.

Table VII shows us to what extent combat experience confirms the invincibility of missiles.

Several points need to be made:

1. The only inventory missile approaching reasonable lethality is the Sidewinder D, despite the fact that it is launched out-of-envelope 4 times as often as the Sparrow and is only slightly more reliable.

2. Out-of-envelope launches (as opposed to desperation launches) should not be discounted as pilot error. In fact, they reflect the inherent tactical limitations of each missile system. Needless to say, no one attributes out-of-envelope gun-firings to the pilot error in order to raise the P_K of guns.

Table VII				
	P_k (kills per trigger squeeze)	Launches out of Envelope	Cost Per Munition	Reference
Sidewinder B	.17	.39	$ 3,000	6
Sidewinder D	.27	.24	14,000	6
Sparrow D/E	.08	.07	44,000	6
Falcon D	.09	-	39,000(w/mods)	6
SA-2 1/	.005-.02	-	50,000 - 80.000(?)	15
6 Cal .50 (F-86-Korea guns; fixed sight)	.34	-	56 (100 rds)	16
6 Cal .50 guns (computing sight)	.30	-	56 (100 rds)	16

1/ This P_K is probably high, since unsuccessful and undetected launches are not included. The variation covers different periods and launch rates, the lower results being more recent.

3. Despite the oft-heard reassurances that missile effectiveness in SEA would improve as pilot training and maintenance improved, the p_k time trends have been constant or even slightly decreasing, indicating perhaps improved enemy missile-evading tactics.

4. Given the extraordinarily low SA-2 p_k (due mostly to the ease of outmaneuvering the SAM and aided by its centroid tendencies plus ECM) and the very low engagement rate (only at most 5% of the sorties entering Route Package VI are fired upon) it is clear that the SAM is not a significant factor in air war losses over NVN. Yet it was the widespread belief in the high lethality of the SAM that led us to attempt the disastrous early low level tactics of 1965 (5% AAA attrition per sortie for the Navy, 8% for the USAF).

5. The air-to-air missiles, in addition to their reliability and out-of-envelope launch problems, are being regularly defeated by maneuvers which take advantage of the combined effect of inherent missile guidance lags, seeker limits and g limits. To illustrate the inherent maneuver limitations of the Sidewinder and Sparrow, Figures II-V show acceptable launch envelopes based on the perfect guidance, noise-free simulation programs in use at Eglin AF Base (ATBA).

6. Against pilots more skilled in missile-defeating tactics, we can expect p_k's lower than those being obtained currently. Nevertheless, the air-to-air missile, despite its probably inherent reliability and maneuverability limitations, gives us a valuable tactical option, i.e., using it we can force the enemy into energy-decreasing evasive maneuvers which make him vulnerable to a subsequent gun attack (provided we are equipped with a good air-to-cannon). It should be noted that it is not necessary to have an expensive or complex missile to achieve this tactical option; in fact, current experience would indicate that the simpler the missile the more likely it is to be effective.

Case IV -- Air-to-ground Missiles: Recently a school of thought has arisen in the avionics community that contends that bombing computers won't work well enough to be useful - consequently, accuracy must be built into the ordnance in the form of terminal guidance.

Fig. II

Launch Envelope for Sparrow (AIM 7E)-
Launch Velocity = Target Velocity = M.9
Altitude = 10,000'; no maneuver

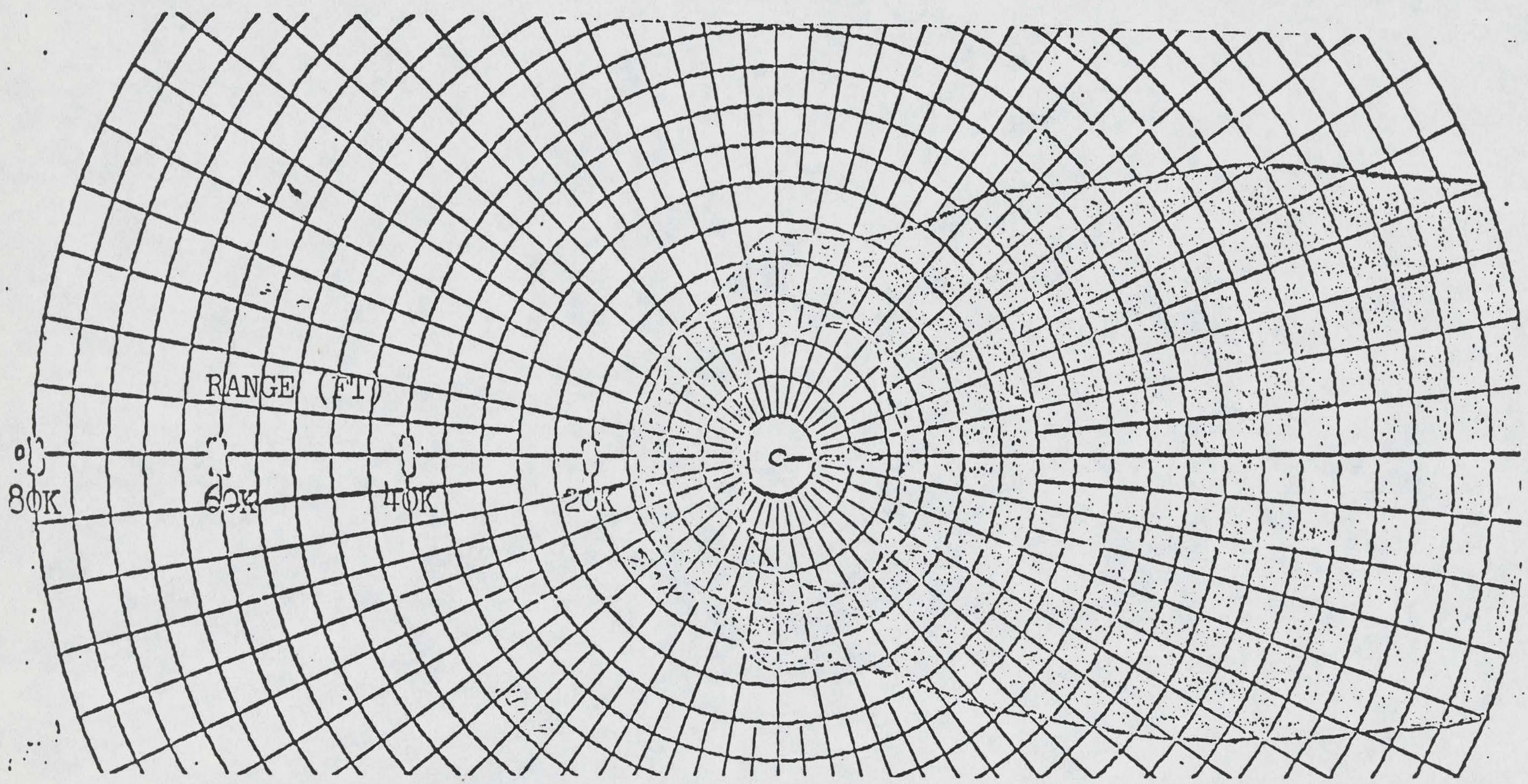


Fig. III

Launch Envleope for Sparrow (AIM 7E)-
Launch Velocity = Target Velocity = M.9
Altitude = 7500'; 5G "S" turn
to $\pm 30^{o}$ with 1.5 second delay

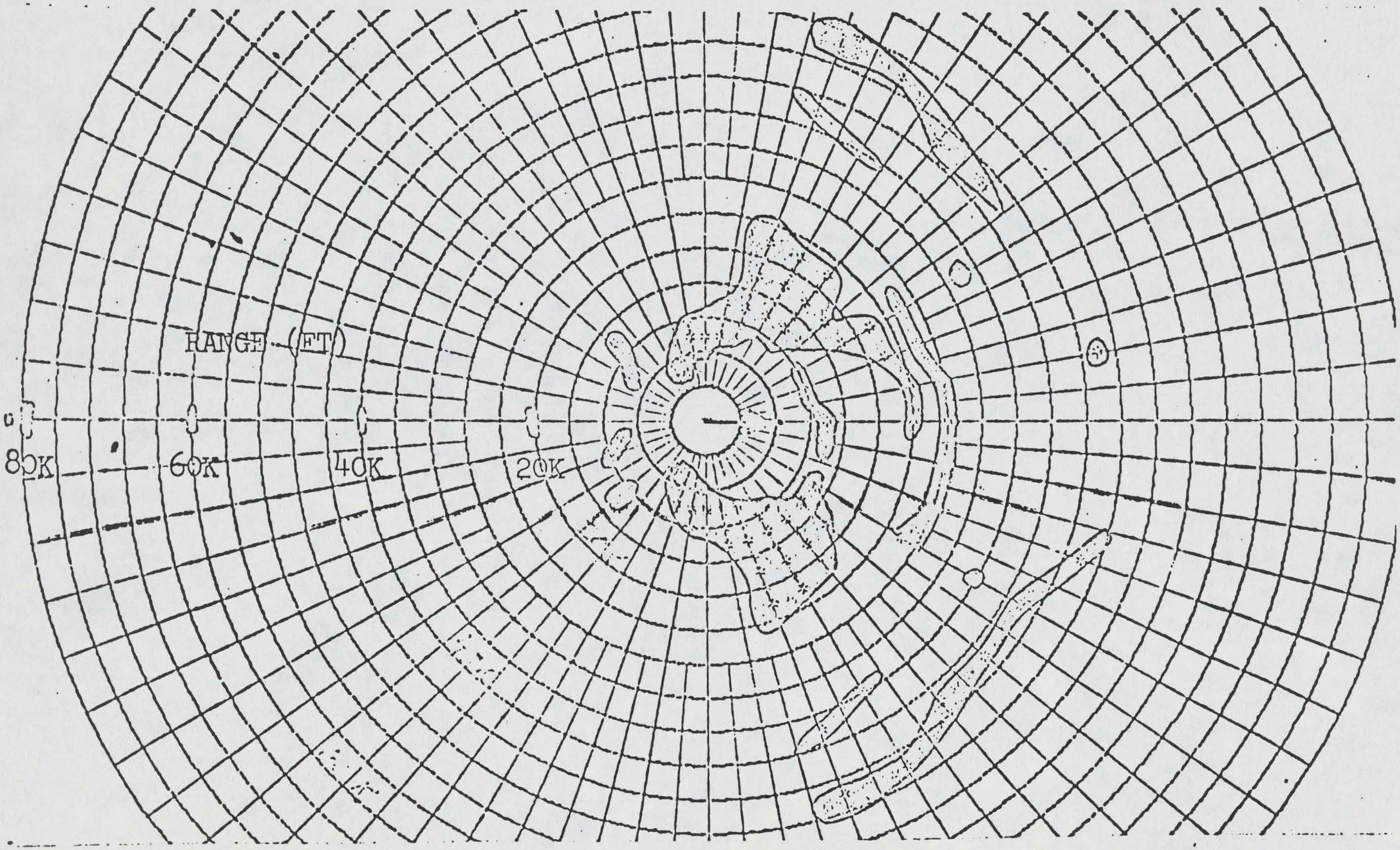
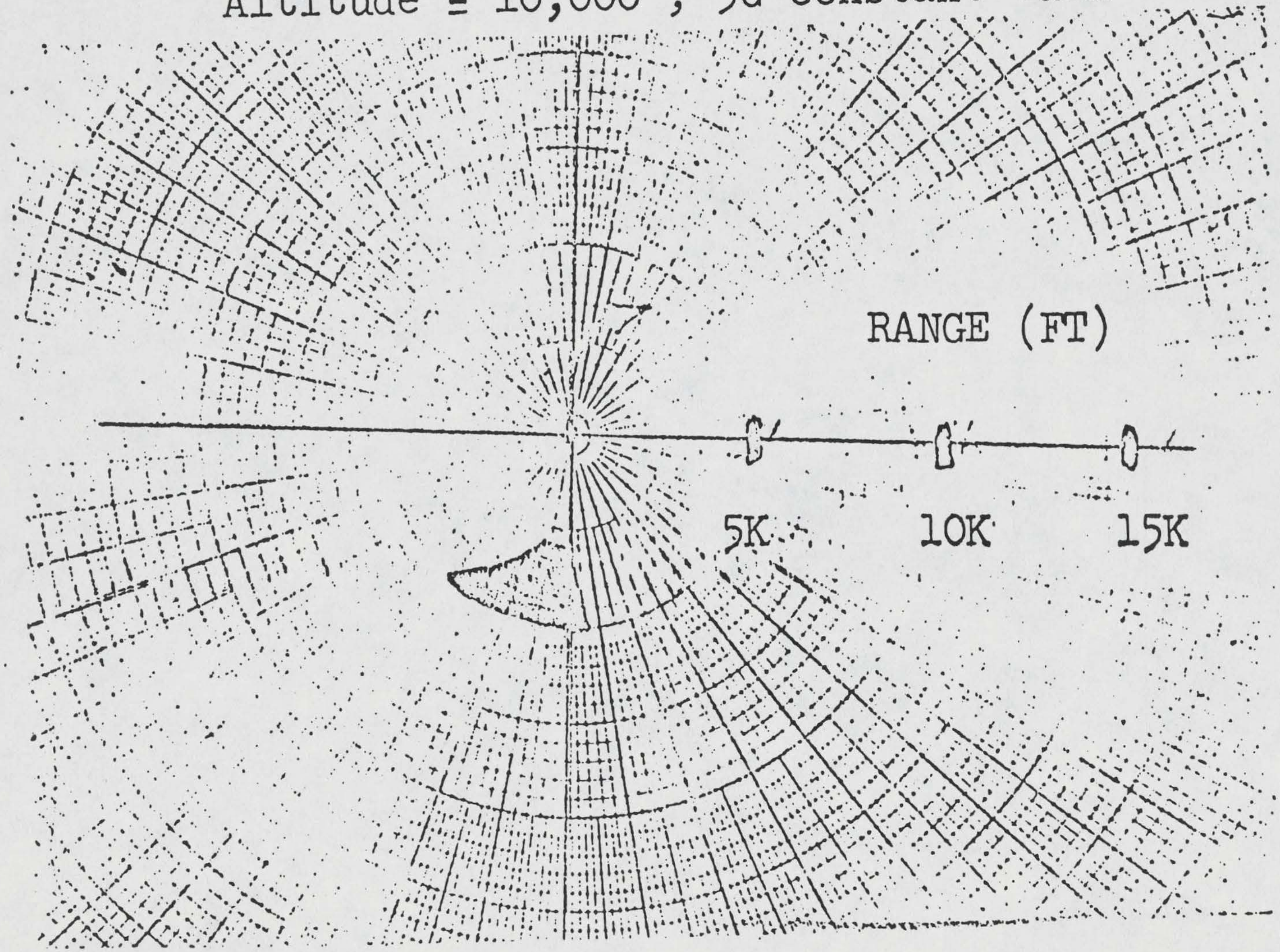


Fig. V

Launch Envelope for Sidewinder (AIM 9B)

Launch Velocity = Target Velocity = M.9

Altitude = 10,000'; 5G constant turn



Actually, there is a long and generally ignored history of air-to-ground missile development dating back to WW II. WW II saw the development of the American AZON, RAZON and TARZON, the German Fritz X and Henschel Hs293 plus several TV-guided and photo-homing bombs. The American developments, which led to the first Bullpups, were radio-controlled pilot-steerable glide bombs (later Bullpups finally added thrust, as in the Hs 293, to obtain reasonable standoff). The Hs 293 obtained good results against shipping and somewhat less satisfactory results in defended areas (the Henschel designers were realistic enough to realize that a separate missile operator was needed for missile control during the breakaway maneuver; this has not yet occured to the Bullpup enthusiasts). AZON, RAZON, TARZON and Bullpup were all uniformly disappointing in combat, the first three due to unacceptable control dynamics and the latter due to the highly vulnerable long straight flight path required for tracking up to impact.

Many radar and IR air-to-ground missile developments have been and are being pursued. Radar has shown a notable lack of success against anything except corner reflectors; IR missiles could have limited special-purpose applications against hot targets (through simple countermeasures such as bags of rice thrown over truck hoods must be kept in mind). The first real whiff of success in the air-to-ground missile business has come with the development of the Walleye; the experience with this weapon deserves close attention:

1. There is no doubt that at least the simpler EO weapons will hit within 10-15' CEP any high contrast target they can be locked onto. Whether the reliability of such weapons will ever exceed 80% is not obvious.

2. The difficulty of the pilot's lock-on task is not widely appreciated. The image, as in any airborne TV, has extremely poor resolution; the jitter in the image due to both aircraft flexibility and electronic noise is remarkable. The pilot's task consists of

rolling in and putting the pipper on the target switching to the TV screen to acquire the target, aligning the aircraft to center the target in the gate and then attempting to lock-on. This process generally takes 15 seconds as opposed to 6-8 seconds for iron sight combat drops. To make the task manageable, shallow dives (approximately 20°) are used. All this adds up to an extremely vulnerable approach tactic (attrition goes up exponentially with length of straight tracking flight). Combat results show the effect of poor resolution (despite the specially selected high contrast targets) and long tracking times: average slant range at release is only 8900'; Walleye sorties take 4 times as many hits as iron bomb sorties (Reference 17). In other words, the pilot exposure in a Walleye release is as unacceptable as during a Bullpup release.

3. The targets most frequently selected in SEA have been large buildings and bridges. The large buildings with interior contrast windows are ideal for lock-on (Note 2); unfortunately, it takes quite a few 800 lb. warheads to destroy a large building such as a power plant; single detonations of Walleye inside the windows of large buildings have not shown any destruction of roofs or walls in the available BDA. Results against soft wooden bridges have been excellent; a two aircraft attack has been generally sufficient. This compares with the JMEM prediction of 20 A-4 sorties (using 500 pound bombs) on the somewhat harder truss bridge (combat results are slightly better than JMEM prediction). We can therefore peg the comparison in aircraft lost per soft bridge destroyed at somewhere between equal losses and half the losses when using Walleye (taking into account 4 times higher attrition per sortie for Walleye). The balance swings strongly in favor of the iron bomb when buildings as large or larger than 130' x 65' are considered (6 iron bomb A-4 sorties per building, according to the JMEM) or when steel and concrete bridges are of interest.

Against hard bridges where a pier must be destroyed in order to drop a span, the Walleye results have been disappointing due to its inability to hold lock on the low contrast pier. Walleyes have registered three direct hits on the Thanh Hoa bridge; BDA shows the results to have been three bent girders. Other girder bridges have required 5-6 attempts per span destroyed due to lock-on difficulties, low contrast, lack of warhead effectiveness and lock-shifting to invulnerable girders.

4. When considering the substantial investments necessary to build up inventories of Walleye at $20,000 unit investment, the question of countermeasures must be considered. The Hanoi newspaper has published a complete description of the weapon and points out that smoke and flares can be used to countermeasure it. Other interesting and simple countermeasures are camouflage of interior contrast of buildings and bridges (especially piers) or AAA guns for high value point target defense. The latter defense should be even more effective against the larger Condor missile; its effectiveness is attested to by the fact that American AAA shot down 80% of German V-1's launched against the Brussels-Antwerp area (note that the area defense problem is far more difficult than point defense since it involves high deflection gunnery).

5. In summary, it can be concluded that the Walleye is an excellent special purpose weapon for a restricted set of targets, namely, those targets that have high value, high contrast, are vulnerable to 1 or 2 Walleye impacts and are not heavily defended (or countermeasured) (Note 3). These limitations are reflected in the low SEA consumption rate (10-15 missiles per month) and recently reduced Service production requests.

One other class of air-to-ground missiles in which we have invested heavily, despite the ineffectiveness of the SAM, are the anti-radiation missiles, Shrike (at $11,000 per copy) and ARM (at $120,000 per copy). These share the unreliability of the radar air-to-air missiles plus the special angular resolution and target emitter shut-down problems of any home-on-emission system. Even worse, a successful impact rarely results in more than light fragmentation damage (Note 4).

Table VIII shows a summary of our experience in the air-to-ground missile business. Note the large combat degradations of the pilot-controlled missiles.

Table VIII

AIR-TO-SURFACE MISSILE RESULTS

Missile	CEP	Hits	Condition	Reference
Hs 293	15'	--	Peacetime (7 km range)	18
	35'	-	Combat (4-20 km)	
RAZON	60'	-	Peacetime (15,000')	18
	170'		Combat (15,000')	
Bullpup	30'	-	Peacetime (test)	18
	56'	-	Peacetime (Squadron)	19
	100-150'	-	Combat	20
Walleye	10-15'	-	Peacetime	21
	-	.49-.78 3/	Combat	7
Shrike 2/	-	.14	Combat	8
Standard ARM 1/	-	.06	Peacetime	9

1/ VX-5 Advance Evaluation Note estimates .20 successful "suppression" kills.

2/ Based on pilot claims for impacts in target area, not necessarily kills.

3/ Based on pilot claims (lower number is AF claims, higher number is USN claims).

Case V -- Detection and Navigation: Since WW I, fighter pilots have been aware of the overwhelming importance of detecting enemy aircraft first. The unequalled combat record of the Flying Tigers (20:1 exchange ratio) was based in large part on General Chennault's careful development of a primitive but amazingly effective early warning net based on spies, observers and telephone/messenger communications. The WW II British-developed manual radar scope plus plotting board GCI system is essentially the same as the system used by both sides in Korea, today's Soviet and North Vietnamese GCI, and today's FAA air traffic control. Automatic track-while-scan systems such as the SAGE and the ATDS aboard the E-2A (and presumably the future AWACS) have not proved successful (independently of their lack of low-level capability) in automatic mode due to unreliability, track initiation delays, inability to cope with clutter, track-weaving and hard maneuvers (an inherent problem of low data rate, high angular noise automatic systems) plus far greater vulnerability to simple countermeasures such as chaff. These are all problems in which the performance of experienced human operators is considerably superior to that of automatic trackers.

Our NVN combat experience shows that our pilots have had to rely on classical visual detection for air combat:

1. The offshore radar early-warning aircraft have not been successful in warning pilots of imminent attack, due to both friendly traffic and clutter problems.

2. On-board radars have been an insignificant source of air-to-air detections - 14%, according to the Red Baron data, for air-to-air missions using search radar.

The latter is an important point, since most technical people feel that a modern fighter aircraft without search radar is inconceivable. It is instructive to examine the reasons for the failure of on-board radar, since they are not likely to change in future tactical combat (as opposed to night fighting):

1. Pilots in NVN are unwilling to use their radar during combat area ingress and egress, since it enhances the enemy's early warning and tracking capability by 100 to 200 miles (once the enemy deploys aircraft with X-band warning, pilots will be even more unwilling to use radar). This was confirmed by Eglin AFB tests of the F-105 radar, which was easily detected and DF'ed at 200 miles on the deck (over the radar horizon). Strangely enough, the full implications of these tests have not been applied to the question of the utility of terrain following radars. In the combat zone, of course, F-4 pilots are constrained to turn on their radars if they wish to use the Sparrow missile.

2. There are few enemy aircraft to be found in the scan coverage of fighter radars; enemy GCI vectors them either on a wide offset course or down low in the clutter (consequently, almost all our initial detections are made visually in the rear hemisphere). The latter problem would, of course, be solved by look-down if such a capability could be bought. Unfortunately, look-down performance analyses generally assume stationary Gaussian clutter noise in order to allow linear filter theory to be applied. Because clutter is neither Gaussian (nor even random noise in a rigorous sense) nor stationary (Note 5), linear filters are far from optimum and consequently actual look-down tests show very disappointing results when compared with theory. From the point of view of tactical employment, it must be remembered that a mere improvement in clutter rejection is of no interest - either we can detect enemy aircraft reliably in clutter or we can't.

NVN combat experience also sheds light on the interesting detection problem of SAM warning. Apart from the usual lack of reliability, SAM warning gear has been rapidly losing effectiveness due to a heavy (and predictable) increase in enemy spoofing. Our pilots are almost back in the same situation as they were in 1965 - today's radar warning does show the presence of SAM sites but only continuous visual search gives reliable indication of SAM launches.

In navigation, SEA has provided us with the first combat test of an inertial platform (in the F-4C/D); the results are not encouraging. The platforms are so unreliable that they require continual checking against other aircraft in the flight and against dead reckoning in order to determine which platforms are still working. It appears that the primary (and perfectly satisfactory) navigation modes for all units in NVN are dead reckoning and TACAN. It must be remembered that in the NVN situation, as opposed to strategic missions, the pilots become intimately familiar with local terrain features - this familiarity remains their most important navigational aid.

The question of suitable measures in navigational devices, particularly inertial platforms, has not been satisfactorily investigated. The usual specification of x miles CEP per hour is unrelated to the actual behavior of the observed errors for inertial systems, which are roughly sinusoids of exponentially increasing amplitude. The amplitude itself is highly sensitive to both initial misalignment and maneuvers, neither of which are realistically introduced in testing. Unfortunately, most measurements available in a realistic maintenance environment record only terminal errors (en-route errors can be considerably larger). Nevertheless, Figure VI shows a summary of error data for F-4 platforms. The results show the uselessness of the 3 mile per hour specification quoted for this equipment; they also explain why dead reckoning is still so heavily emphasized in pilot and navigator training.

CONCLUSIONS

1. Current and past avionics effectiveness analyses and predictions have failed to show any correlation with combat results; both claimed accuracies and P_K's have been off (always in the same direction) by as much as an order of magnitude. Until the methodologies and data inputs used for such analyses demonstrate at least rough correlation with combat results, they will continue to be scientifically invalid and useless for decision-making purposes.

2. Avionics costing has been as unrealistic as avionics effectiveness; results that show major systems 10 year costs of less than 5 times investment costs are simply not credible.

3. Peacetime testing procedures and organizational motivations that allow systems as ineffective and unreliable as some of those we now have in combat to proceed into inventory can and should be reformed. Test environments should not be created to show equipments to their best advantage; these environments should simply use tactical experience to reproduce the most stringent aspects of the combat situation.

Given the present state of avionics effectiveness analysis, no electronic equipment should be approved for production and no procurement commitments should be made until the results of rigorous simulated combat environment tests have been analyzed.

4. Combat and test results indicate that there has been and continues to be a serious misallocation of resources in tactical air hardware amounting to billions of dollars in the last ten years. We simply didn't get what we paid for, nor is there much indication that we are likely to get it in the future.

5. In the past, we have attempted to design "management by exception" avionics systems where the pilot's only task was intended to be surveillance of the warning panel; or, even worse, we have attempted to build systems to eliminate the pilot's supposedly clumsy and unintelligent responses from the loop. This philosophy has resulted in equipment designed for hands-off combat (e.g., the F-106/MA-1) and push-button attack missions (e.g., the Target and Home button approach of the A-6A). We have missed these goals by large and expensive margins and have ruined the performance of our aircraft in the process. We should cease designing and procuring equipment to automate functions which pilots have performed satisfactorily in the past. Instead, our avionics equipment should be designed exclusively to help the pilot achieve demonstrable improvements in mission-essential tasks.

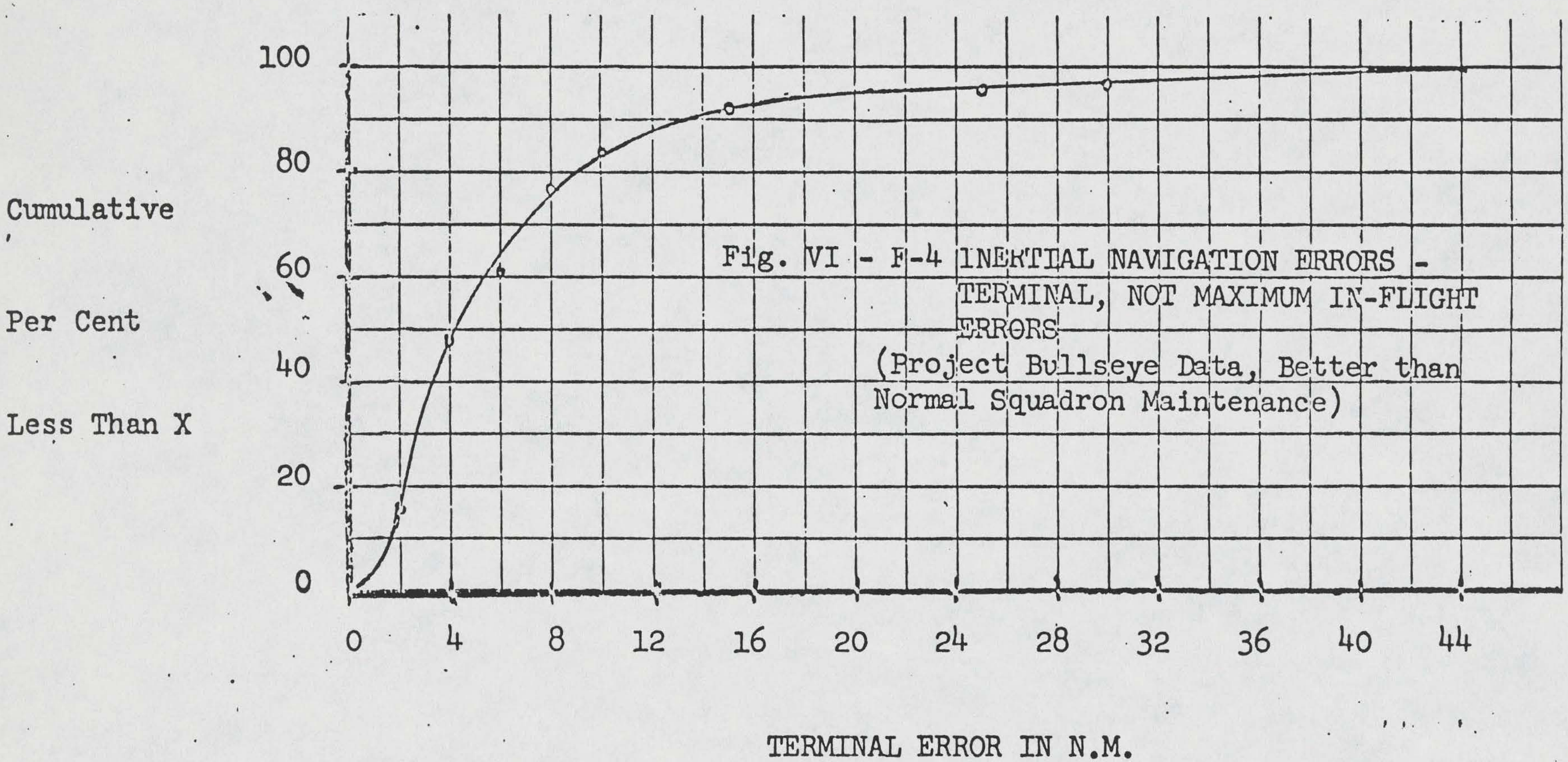


Fig. VI - F-4 INERTIAL NAVIGATION ERRORS - TERMINAL, NOT MAXIMUM IN-FLIGHT ERRORS
(Project Bullseye Data, Better than Normal Squadron Maintenance)

NOTES:

1. R&D cost of approximately $.5B, fire control system $2M per copy and missile $200K per copy.

2. Interior contrast is very important for Walleye; if it is locked to an exterior edge it will generally seek a corner and consequently miss 3 out of 4 times, since three of the four available corner quadrants lack target.

3. An ideal target for the Walleye, as for the Bullpup and the WW II Hs 293, is the ship (in the absence of high contrast wakes).

4. This ineffectiveness has reached the point where theater reports do not use SAM radar destruction as a mission objective; "suppression" is the criterion of mission success and encompasses anything from a near miss to the shut-down of a spoofing radar.

5. Actual land clutter varies deterministically from one terrain feature to the next; its wave forms are not well described by sinusoids nor is its amplitude normally distributed.

BIBLIOGRAPHY

1. USAF Specialized Close Air Support Aircraft Weapon System Study (A-X) - Final Report, 1 September 1967, Northrop Corporation plus backup data provided by Mr. D. Gregor.

2. Tactical Development, August 1942-May 1945, 9 July 1945, prepared by Eighth AF and AAF Evaluation Board (ETO), plus working papers of the Eighth AF Operational Research Section.

3. USN-OP 506 Memo, Subject: A-6 Performance and Reliability Based on Patuxent River Data.

4. USAF Tactical Fighter Weapons Center Memo, Memo of 13 March 1968, Subject: Transmittal of Harvest Reaper Analyses Results.

5. The Analysis of the Reliability Model of the MA-1 AWCIS of the F-106 Aircraft, March 1965, ARINC 491.

6. Red Baron Data Base, WSEG.

7. Summary of USN and USAF Walleye Combat Firings Through 28 November 1967, Naval Fleet Missile Analysis and Evaluation Group.

8. Shrike Mission Performance Summary of Vietnam Firings, November 1967, Naval Fleet Missile Systems Analysis and Evaluation Group.

9. A-6B/Standard ARM Mod 0 Weapons System, USN VX-5 Advanced Evaluation Note, 14 March 1968.

10. Fleet Exercises Reports: USS Kittyhawk Exercise, Operation Grey Ghost, Yankee Doodle.

11. Combat Bullseye Final Report - F-4.

12. A Review of Avionics and Delivery Accuracy, P.M. Sprey, October 1967, OSD(SA) Staff Study.

13. Combat Bullseye Final Report - F-105.

14. Memo from Op-05W to SecNav, 4 May 1967, Subject; Accuracy of the A-6A Weapons System in the Combat Environment.

15. Raw data from NVN

16. F-86 vs. MiG-15, 19 May 1954, AIWR, U. Chicago.

17. "Bon Homme Richard" Southeast Asia Cruise De-Briefing

18. The Effect of Combat on the Accuracy of Various Human Operator Control Systems, Walker and DeSocio, April 64, Report No. 9, Norman K. Walker Associates.

19. A-7A Bullpup Employment, 7 November 1967, VX-5 - Advance Evaluation Note.

20. Naval Weapons Center assessment transmitted to USAF HQ(RDQ), January 1968.

21. Joint Munitions Effectiveness Manual Coordination Draft, Vol. I, ; Walleye accuracy based on NOTS test range data.

22. F-X Tactical Aircraft Design Study - Final Report, 31 May 1968, General Dynamics Fort Worth Division.

23. USN OP-96C2 Memo, 23 January 1968, Subject: A-6 Effectiveness.

24. Gun Ship II Final Report, February 1968, USAF TAWC, Eglin AFB.