Analysis of Operational Issues in Support of the Development of the AN/APS-144 Podded Radar

May 1997

by

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13. ABSTRACT *(Maximum 200 words)*

This report describes the analysis of operational issues regarding the use of the new AIL AN/APS-144 podded radar on aircraft for counterdrug interdiction. It addressed several performance and operational issues associated with use of the radar for air-to-air intercept missions with targeting data provided by the Relocatable-Over-The-Horizon Radar (ROTHR) surveillance system, such as: Radar volume coverage; latency in the C^2 link; intercept geometries; and the effect of target and interceptor speed on probability of target detection. The analyses also address effects of interceptor range restrictions, and the use of alternate end-game tactics. The study further involved analysis of river visibility of four major rivers in South America using a GIS tool and the Defense Mapping Agency's Digital Chart of the World. It is concluded that podded radar intercepts with current ROTHR performance are feasible, and probability of success will increase significantly with planned upgrades. Similarly use of the radar for riverine interdiction is not significantly inhibited by tree obscuration.

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1.0 Introduction.

The AN/APS-144 is currently being developed by AIL Systems, Inc. under funding from the DoD Counterdrug Technology Development Program Office. It is pod-mounted for underwing installation on aircraft such as the Cessna A-37B Dragonfly, for use in counter-drug interdiction operations. After testing and operational demonstration on A-37B aircraft under the sponsorship of USSOUTHCOM, the APS-144 could be employed on suitable interceptors against the typically light aircraft used for smuggling cocoa paste from source sites to remote processing laboratories for cocaine production. The radar is also capable of air-to-ground operations to detect riverine traffic as well as moving ground vehicles.

This report describes the results of analysis conducted in support of the development of the AN/APS-144 radar for use on drug interdiction aircraft. The report addresses three main subjects

- Air-to-air intercept analysis using cueing data from Relocatable Over-The-Horizon Radar (ROTHR)
- End-game analysis
- Riverine visibility analysis

Controlling an interceptor based on ROTHR-generated data is quite different from controlling intercepts using conventional line-of-sight microwave radars. This is because of the ROTHR operating characteristics and available command and control procedures. This report highlights operational conditions where an air-air intercept can be expected to be successful. This report also analyzes visibility of portions of four South American rivers when viewed by the podded radar equipped aircraft flying different surveillance trajectories.

General conclusions of these analyses are:

- With the current performance of the ROTHR surveillance system, command and control network and the APS-144, intercepts of suspect aircraft in the ROTHR surveillance region have a reasonable probability of success
- Proposed improvements in ROTHR performance, associated with improved command and control technology, possibly including real-time communications links, will significantly improve the probability of detection by the interceptor
- Initially, end-game tactics may be constrained to frontal intercepts, but improvements in ROTHR accuracy and command and control will allow the use of all-aspect intercepts as the tactical situation dictates
- Use of the APS-144 for riverine surveillance is not degraded significantly by tree obscuration in typical South American river scenarios

The analysis was conducted by SAIC in support of the DoD Counterdrug Technology Development Program Office, US Naval Surface Warfare Center, Dahlgren, VA.

2.0 Air-to-Air Intercept Analysis

The US has deployed two ROTHRs in support of the war on drugs, one in southern Virginia and one in southeastern Texas. A third installation is planned in Puerto Rico. Together, the two existing radars provide extensive coverage of the Caribbean Region and northern parts of South America. The Puerto Rico site will be able to look deep into South

America, including Peru and parts of Bolivia. The ROTHR network can provide economic surveillance of vast regions of airspace as compared to conventional surface and airborne surveillance radars. The ROTHR can provide tracking data and intercept cues to drug-interdiction aircraft such as the A-37B, which can be used conduct intercepts with the aid of the APS-144.

Several issues are of concern regarding the ROTHR to A-37B/APS-144 interface. The ROTHR is an HF radar. Due to the lower operating frequencies and ionospheric propagation characteristics of ROTHRs, their tracking data is not as accurate as that from conventional microwave ground or airborne surveillance radars. This leads to concerns about the adequacy of ROTHR data to effectively cue an interceptor so that its own radar can pick up the target of interest and complete the intercept. Another issue is the efficacy of the command and control system that provides the cues to the interceptor. ROTHR does not presently provide real-time intercept vectors to the interceptor as in a traditional ground controlled intercept. The target datum is provided to the interceptor with an inherent latency. The older the data, the greater the target datum uncertainty.

2.1 Modeling Interceptor Operations with ROTHR Cueing.

A Monte Carlo model initially developed by the Institute for Defense Analysis (IDA) was used to conduct a variety of parametric studies of issues relating to the operational use of the AN/APS-144 for aircraft interdiction based on cueing from ROTHR. The model, which originally was developed to evaluate the potential utility of the podded radar/ROTHR operations concept proved quite versatile in investigating a range of analysis issues that have arisen during the development of the podded radar and preparation for flight testing and operational demonstration of the A-37B equipped with the radar.

Figure 2.1 shows the general intercept model geometry. It is a **single datum** model, i.e. the interceptor receives a single target datum from the ROTHR with associated position, heading and velocity errors, and flies an intercept trajectory based on that datum in an attempt to detect the target. Slight modifications were made to the model by SAIC to allow for the effects of datum latency - reflecting delay in communicating the datum from the ROTHR to the interceptor, as well as one method of compensating for the latency.

This is a statistical model, that produces visual plots of a user-selected range of intercept scenarios. The user can select the range of interceptor speed, target speed, distance of the datum from the interceptor, the latency of the datum, the range of possible aspect angles, ROTHR target datum position, heading and velocity errors. Also selectable are the interceptor radar range, azimuth coverage and minimum Doppler velocity. The model samples from the position, heading and error distributions to establish the datum, and aspect angle for each iteration. The target is then moved along its true velocity vector from its true initial position, whereas the interceptor is moved along a collision course based on the datum. The model then determines if and for how long the target is in the interceptor's radar volume for each iteration. If latency is present, the model moves the real target along its velocity vector by the distance traveled during the latency period. Similarly, if the latency is being compensated for, the model moves the datum along the "virtual" target velocity vector.

The model runs through a series of iterations, the number of which is also selected by the user and develops a real-time visual display of the relative trajectory of the target with respect to the interceptor's radar volume for the set of cases selected. At the end of each run the model produces overall statistics and a histogram of the distribution of the time the target was within the radar coverage of the interceptor. The probability of target detection

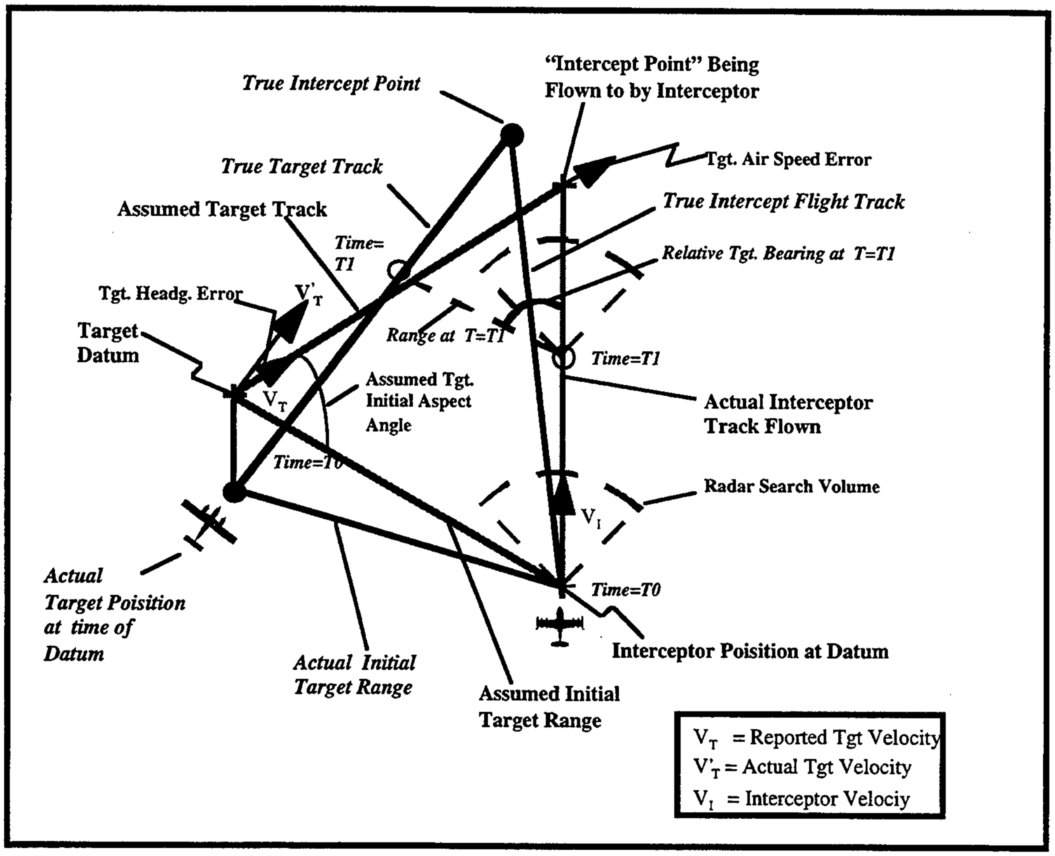

Figure 2.1. Intercept Model Geometry.

for the AN/APS-144 was computed from the probability that the target entered the azimuth scan volume and the probability that it remained there for at least 20 seconds. The latter criteria is a surrogate for detailed modeling of the radar azimuth/elevation search process and essentially assumes that if the target is in the search volume for an entire azimuth/elevation sweep (period) that it is virtually certain of being detected.

Applications of the model include analysis of podded radar scan volume on target detection probability, impact of uncompensated and compensated latency on probability of target detection, contribution of interceptor speed to intercept success, and the use of various target approach tactics to improve intercept success probability.

2.2 Analysis of Podded Radar Azimuth Scan Sector Changes.

One of the early issue that was analyzed arose when consideration was being given to reduce the air-to-air azimuth scan volume of the podded radar from $\pm$ 60 degrees to $\pm$ 30 degrees. One reason for considering the change was that as the radar design progressed, the complete volume sweep duration for the $\pm$ 60 degree scan had doubled from 10 seconds to 20 seconds. By reducing the azimuth scan, the sweep period could remain at 10 seconds. The model was used to evaluate the impact of the alternatives - accept a doubling of the target "revisit" period and retain $\pm$ 60 degrees or cut the sweep azimuth range to $\pm$ 30 degrees and retain the 10 second "revisit" period.

Figure 2.2.1 shows that there is very little loss due to the doubled revisit period with the larger azimuth scan. It also demonstrates a drastic deterioration in probability of target acquisition when the azimuth scan sector is halved, as seen from the lower curves. Providing the interceptor with the datum at 50 NM range compared to 100 NM improves the situation somewhat, but it is still far inferior to the $\pm$ 60 degree results. This clearly indicates that the preferred option for the radar is to accept the increased sweep period (20 seconds) and retain the larger search volume ($\pm$ 60 degrees).

Since reducing the interceptor to target range at the datum from 100 NM to 50 NM showed beneficial results, the effects of reducing it further to 30 NM were analyzed. As seen in Figure 2.2.2, the 30 NM datum has a slight advantage for smal ROTHR errors, but the opposite is true for ROTHR RMS position errors beyond a five miles. As a point of reference ROTHR RMS position error is typically in the range of 6 - 10 NM depending on propagation conditions and target behavior.

These results showed that if the reduced azimuth scan volume was required for design reasons, simply providing a closer datum for the interceptor would not restore the situation to a satisfactory operational level of success.

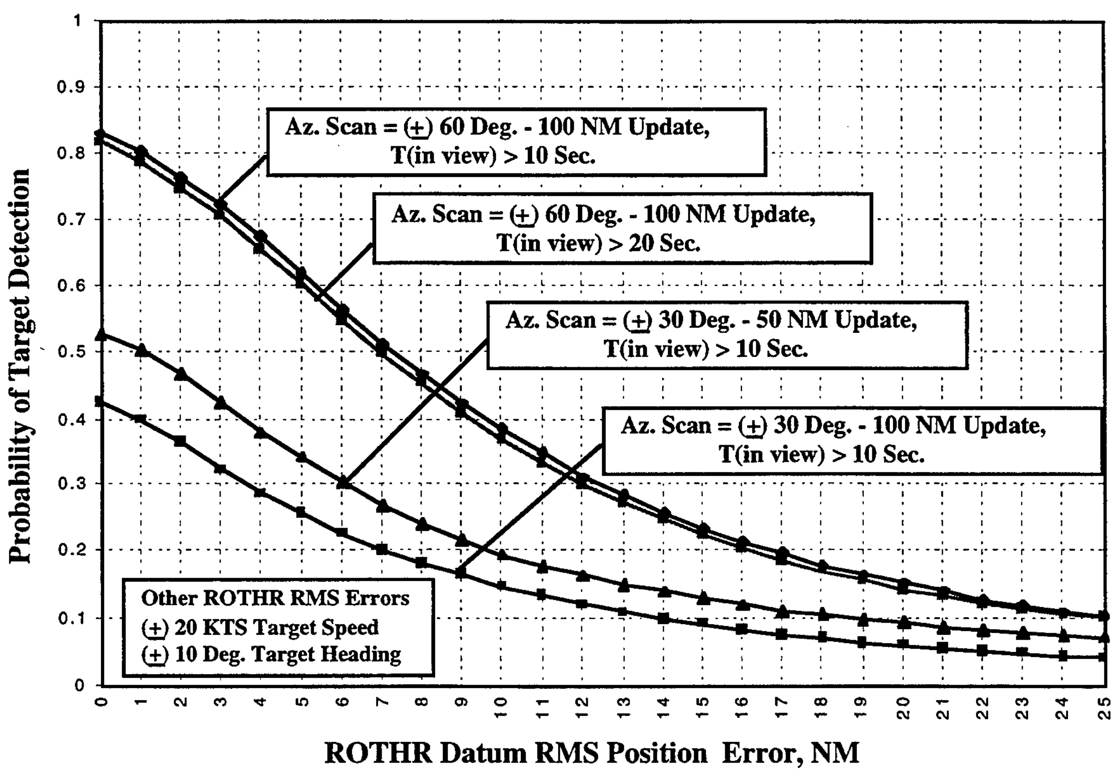

Figure 2.2.1. Impact of Reduced Radar Azimuth Scan and Increased Sweep Period.

Since the above results represent averages over the entire set of intercept geometries from head-on to stern-on, the impact of using more limited intercept geometries was analyzed.

Figure 2.2.3 shows results of conducting intercepts from frontal, beam-frontal, beam-stern and stern aspects. The results indicate that provided ROTHR RMS position errors are less than approximately 8 to 10 NM, Pd is improved by limiting the interceptor to frontal

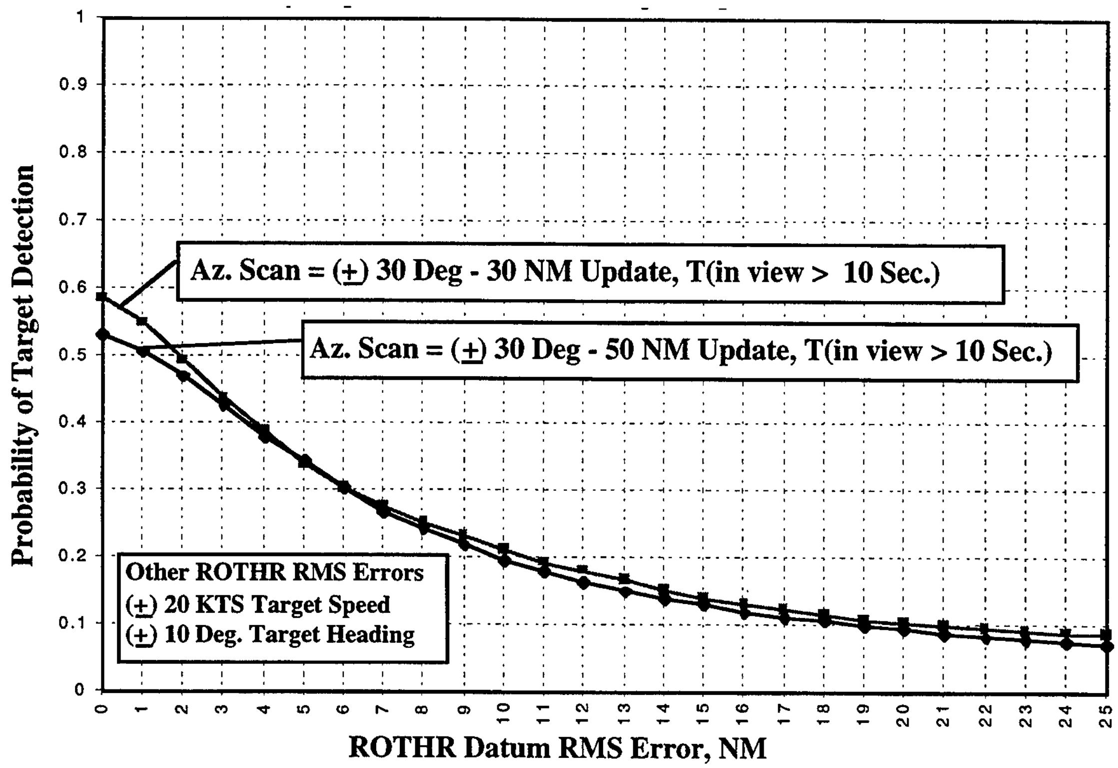

Figure 2.2.2. Effects of Reducing ROTHR Datum Range to 30 Nautical Miles.

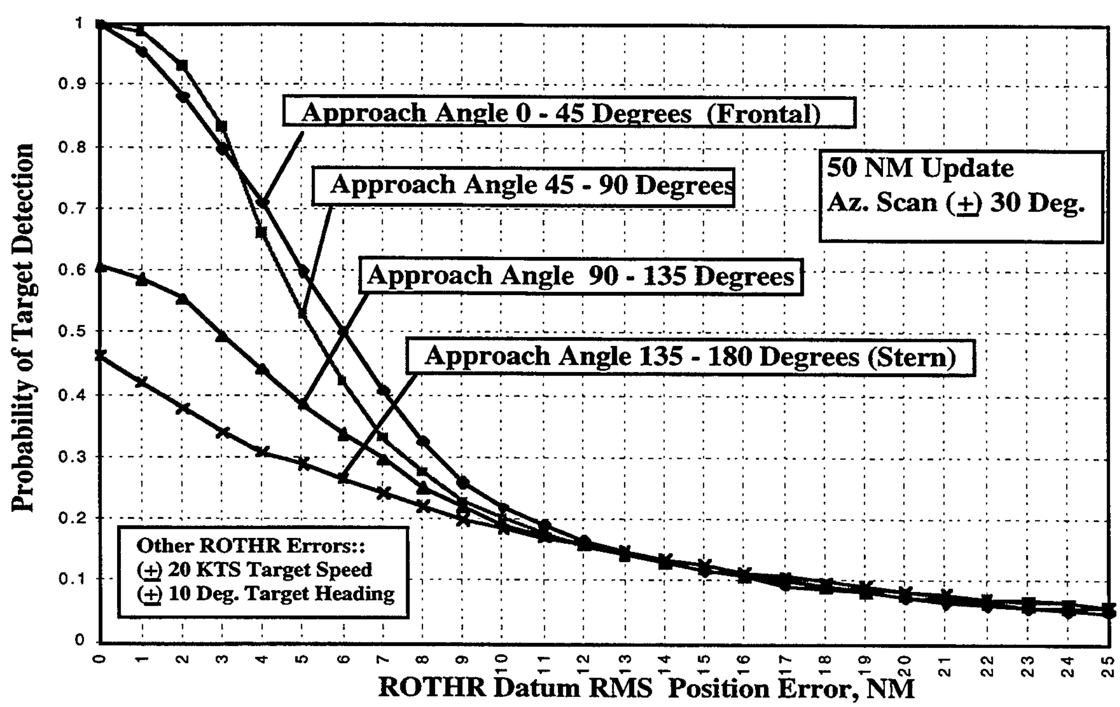

Figure 2.2.3. Comparison of Target Acquisition Probability for Four Intercept Approach Sectors.

approaches. However, at present, this performance is beyond typical ROTHR capability. Stern aspect intercepts are not attractive for any ROTHR error value with a $\pm$ 30 deg. scan.

A major reason for this is the much lower closing speed between the target and interceptor in these cases, which allows the effects of ROTHR errors to propagate for much longer periods than in frontal approaches, resulting in low probability of ever detecting the target. As an example, consider a pure frontal approach versus a pure stern approach. Closing speed in the former case is 8 NM per minute, and in the latter 2 NM per minute, resulting in the interceptor closing to nominal detection range in 4.375 minutes and 17.5 minutes respectively. Thus the effects of the ROTHR position, heading and velocity error used in the intercept solution has four times longer to propagate in the stern approach.

A further consideration is that even if ROTHR error were small enough to improve target detection significantly by use of frontal approaches, there is a potential penalty, not addressed by this analysis. Since typical drug intercepts involve joining up on the target, rather than releasing a missile or firing at it with a gun, the interceptor must be able to "join up" on the target - at least as an initial step. Due to the relatively short range of the podded radar (15 NM) and the high closing speeds (typically 5+ NM per minute), the interceptor crew has very little time available to set up a turning intercept that ensures continous radar contact with the target . Loss of radar contact due to target overshoot and an ensuing reacquisition from the stern may enable the target to maneuver out of the radar search volume. Since the aircraft envisioned for mounting the podded radar may have limited range/endurance (e.g. A-37B), they typically will be confined by fuel restrictions to short time in the intercept area.

Operational tactics can alleviate the frontal conversion situation somewhat, for example by flying slower. However, even if the interceptor were to slow down to 200 KTS, the closure rate is still over 6 NM per minute against a 180 KTS target.

The previous analyses clearly indicate the desirability of retaining the $\pm$ 60 degree azimuth scan as the preferred operational model for the APS-144, since operational tactics will not satisfactorily compensate for the loss in detection probability.

2.3 Analysis of the Impact of ROTHR-Interceptor Communications Link Latency.

The ROTHR datum must be passed to the interceptor via some communications link. Any delay in the transmission of the datum will increase the error in the datum due to target motion during the delay. There are considerations being given to provide means of speeding the transmission of ROTHR data to an interceptor, some of which may involve direct data links via a communication & identification beacon on the interceptor itself.

Parametric analyses were conducted to assess the effect that ROTHR datum latency has on the probability of successful intercept. Figure 2.3.1 shows the results if target motion during latency is uncompensated for, and the interceptor flies to an intercept point based on a latent datum for a nominal datum range of 100 NM, and Figure 2.3.2 shows similar results for a nominal datum range of 50 NM.

Both cases show that uncompensated latency of more than 5 minutes reduces the probability of target detection substantially. Latencies of over 10 minutes essentially make the datum useless.

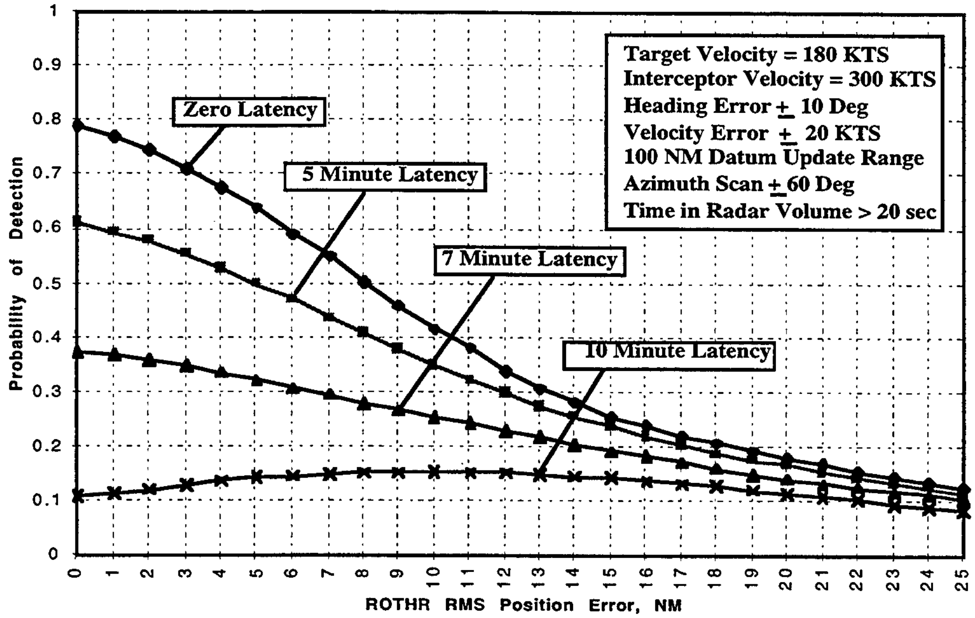

Figure 2.3.1. Probability of Target Detection vs. Uncompensated Latency for a 100 NM Nominal Datum.

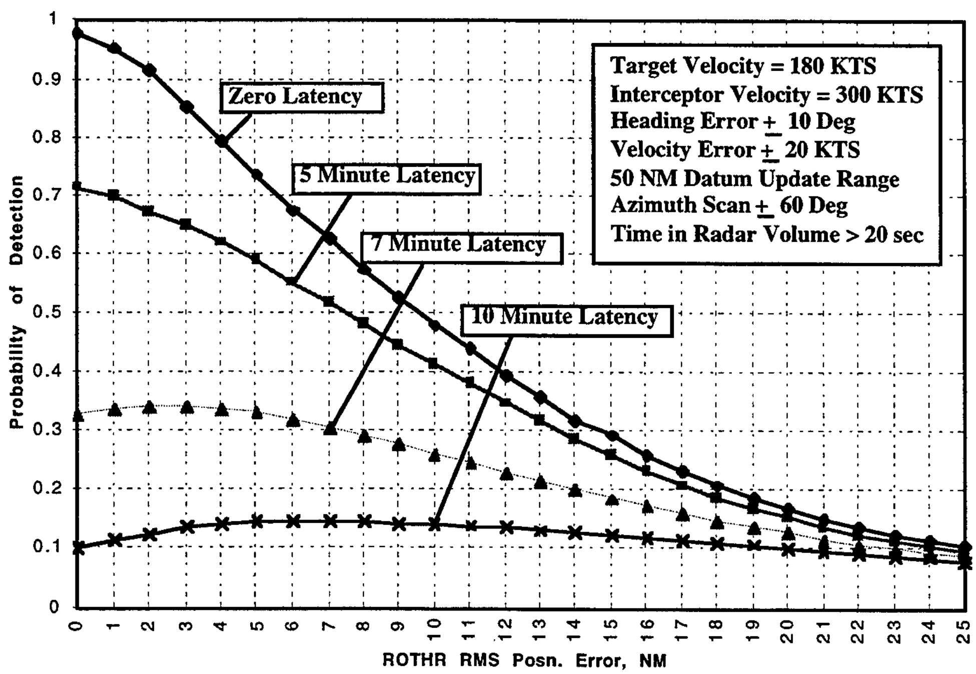

Figure 2.3.2. Probability of Target Detection vs. Uncompensated Latency for a 50 NM Nominal Datum.

An interesting phenomenon is exhibited in the curves with the larger latencies. This is the "peaking" of the probability plot as ROTHR RMS error increases from zero. The explanation is that for a small ROTHR error, latency will add error to an otherwise good datum. As ROTHR error increases, latency errors will combine randomly with ROTHR error, and result in cases where the errors partially cancel out, thus slightly improving the probability of detection. As ROTHR error grows larger, its dominance over the latency error reduces this effect, and the probability decreases again

While the preceding results are of interest in demonstrating the criticality of rapid datum transmission to the interceptor, they are not representative of a real operational scenario. Since the datum information will be time tagged, the interceptor crew and the tasking command authoroty will know how old the datum is. They will use the datum's target position, speed and heading to project it to a current position prior to computing their intercept course (either with an on-board computer or by ground-based C^2 assets). Such compensation can reduce the latency effect - **provided the target proceeds on, or close to, the datum velocity vector**. This compensation method was introduced into the intercept simulation model, and parametric runs were made to compare to the uncompensated cases. Figure 2.3.3 and Figure 2.3.4 show these, for a 100 NM and a 50 NM nominal datum range respectively. It is seen, that latency compensation provides a clear advantage for most situations

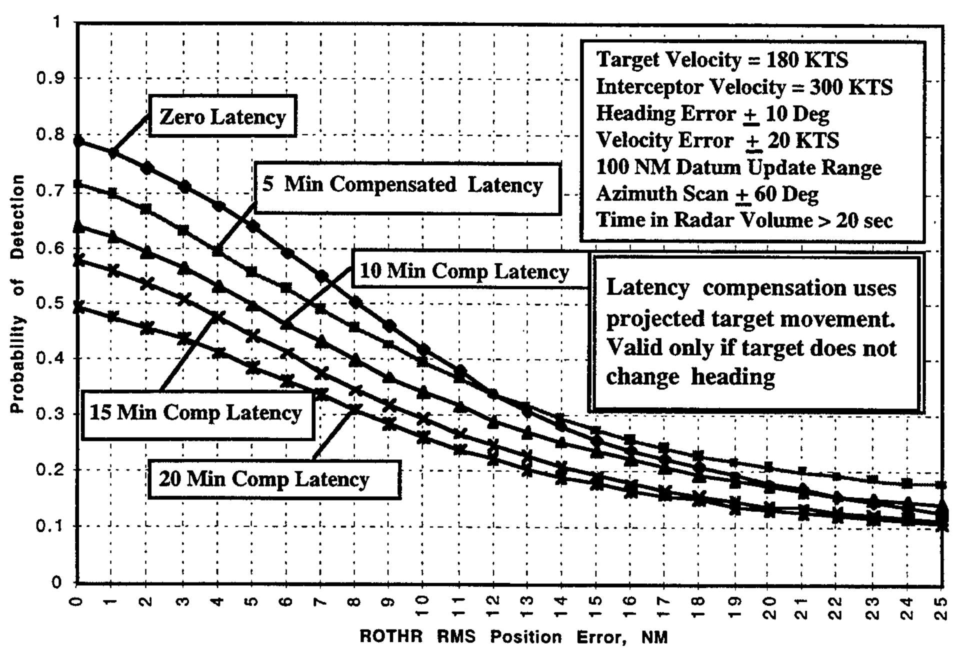

Figure 2.3.3 Probability of Target Detection vs. Compensated Latency for a 100 NM Nominal Datum.

Figure 2.3.5 contains a comparison of the probability of target detection for uncompensated and compensated latency of 5 minutes for a 50 NM nominal datum. This shows that the compensation algorithm is generally only effective for this case if ROTHR datum error is below 11 nautical miles. Figure 2.3.6, which shows the case for 10 minute latency and 50 NM nominal datum, does show a major improvement for the compensation algorithm. The results are similar for a 100 NM nominal update, although the compensation shows somewhat more improvement as compared to no compensation for a 5 minute latency . The results for 5 minute and 10 minute latencies are shown in Figure 2.3.7 and 2.3.8.

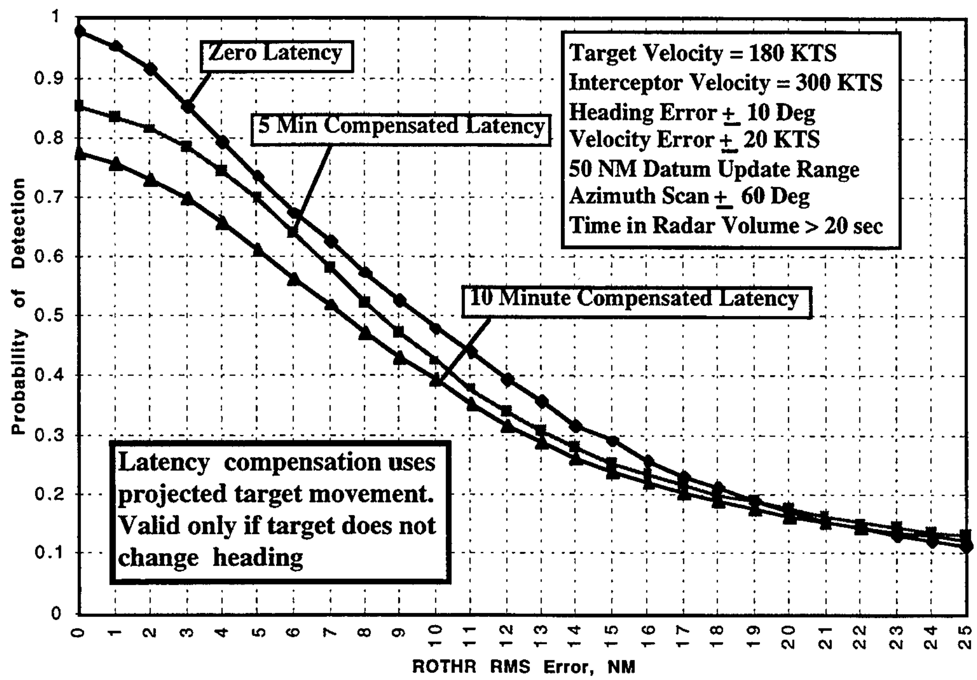

Figure 2.3.4. Probability of Target Detection vs. Compensated Latency for a 50 NM Nominal Datum.

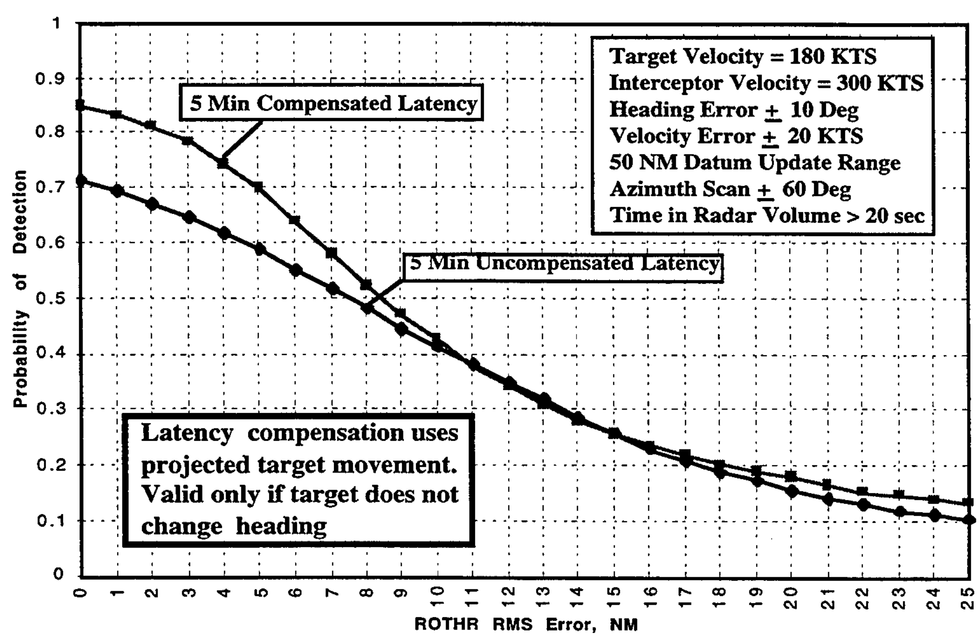

Figure 2.3.5. Five Minute Uncompensated and Compensated Latency-50 NM Datum.

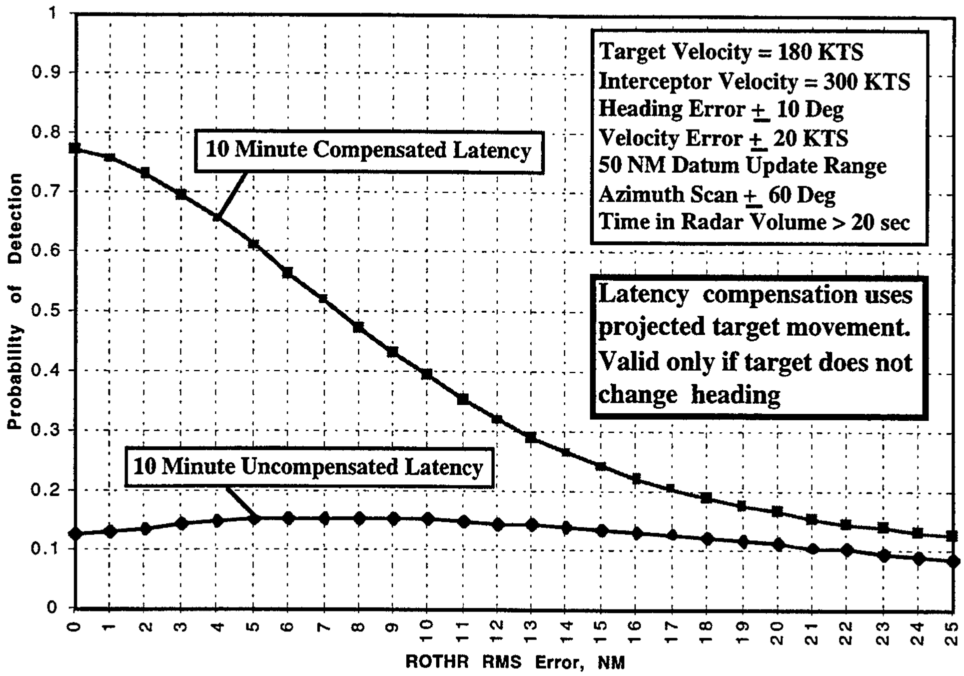

Figure 2.3.6. Ten Minute Uncompensated and Compensated Latency-50 NM Datum.

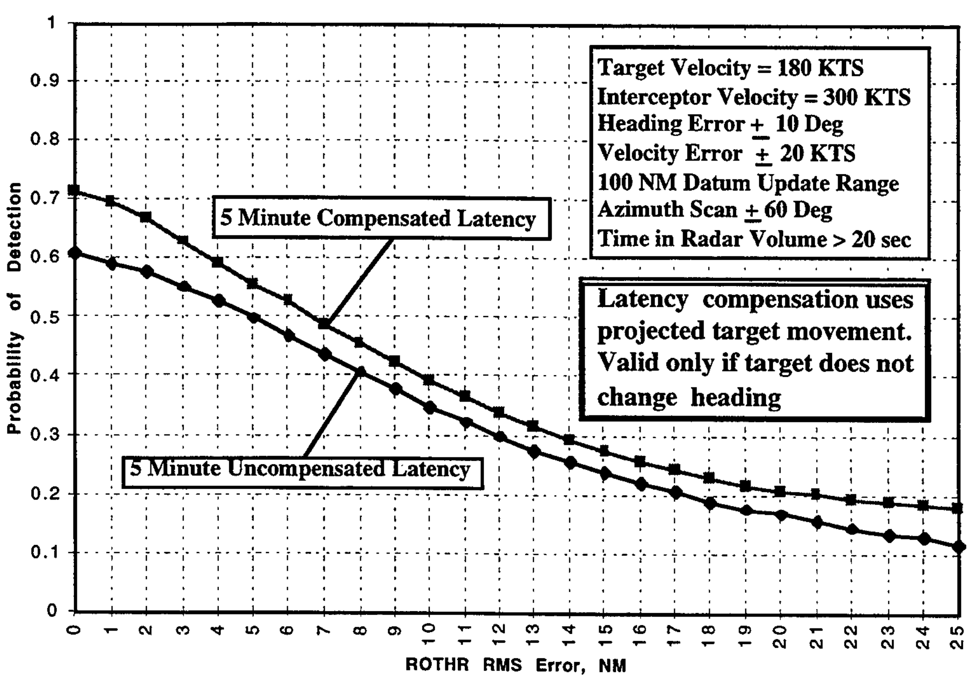

Figure 2.3.7. Five Minute Uncompensated and Compensated Latency-100 NM Datum.

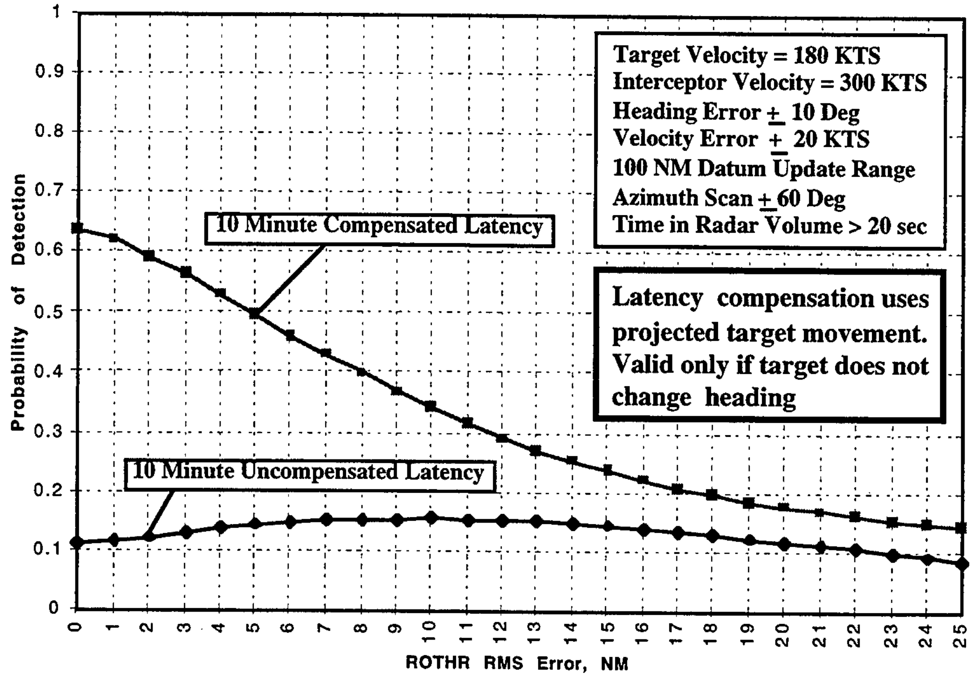

Figure 2.3.8. Ten Minute Uncompensated and Compensated Latency-100 NM Datum.

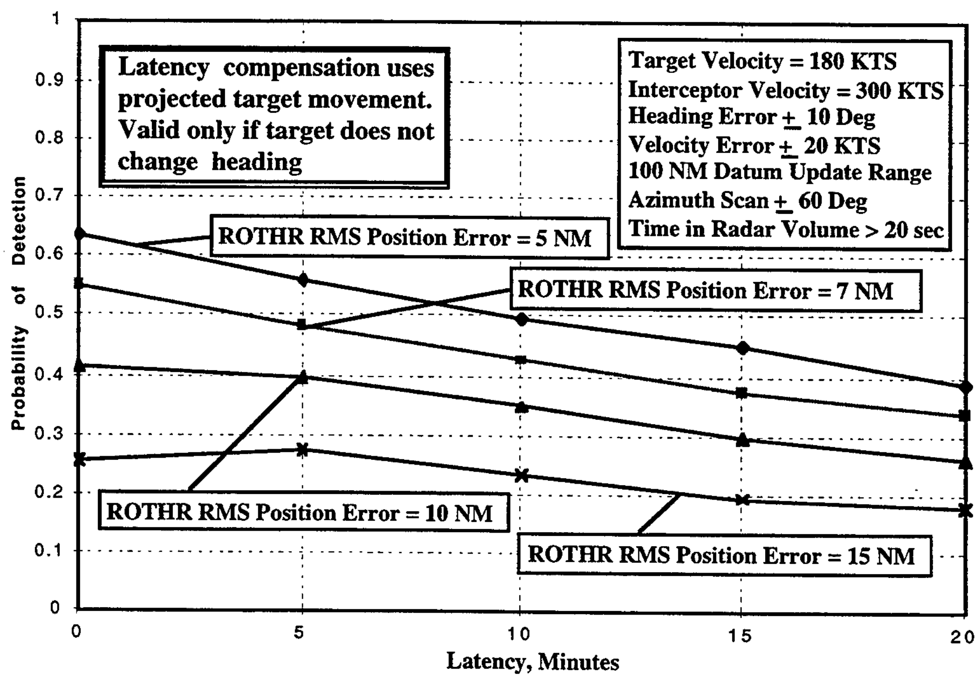

Figure 2.3.9. Detection Probability vs. Compensated Latency & ROTHR RMS Position Error for a 100 NM Nominal Datum.

The results depicted in Figure 2.3.9 provide insight into the relationship between compensated latency and various ROTHR RMS position errors for a 100 NM nominal datum. These indicate that Pd decreases linearly, at a uniform slope across for small RMS position errors, but exhibits the "peaking" phenomenon as position error increases.

The general observation can be made, that latency in the communications link from the ROTHR to the podded radar interceptor has to be kept to a minimum. Use of latency compensation alone does not resolve the problem - ROTHR accuracy must also improve. Even with improved ROTHR accuracy, the latency compensation will deteriorate quickly if the target makes a significant heading change during the latency period. Small course deviations are somewhat compensated for by the random ± 10 degree heading distribution used in the model.

2.4. Analysis of Intercept Tactics.

As can be seen from the previous sections, many factors play a role in determining a successful target acquisition with the podded radar using ROTHR cueing. As has been shown in Section 2.2, use of selective intercept setups can improve detection rates as compared to unconstrained geometries, provided other impact factors are right.

In support of planning for initial operational flight demonstrations of the A-37B with the podded radar, further parametric analysis cases were run to gain insight into the effect of selective intercept approach sectors, but using the APS-144 ± 60 degree radar azimuth scan capability as compared to the ± 30 degree scan in Section 2.2.

As a baseline case, Figure 2.4.1 compares probability of acquisition over four approach sectors (frontal, frontal-beam, stern-beam and stern) versus ROTHR RMS position error **assuming** zero latency and 50 NM datum. This shows, that all approach sectors generate

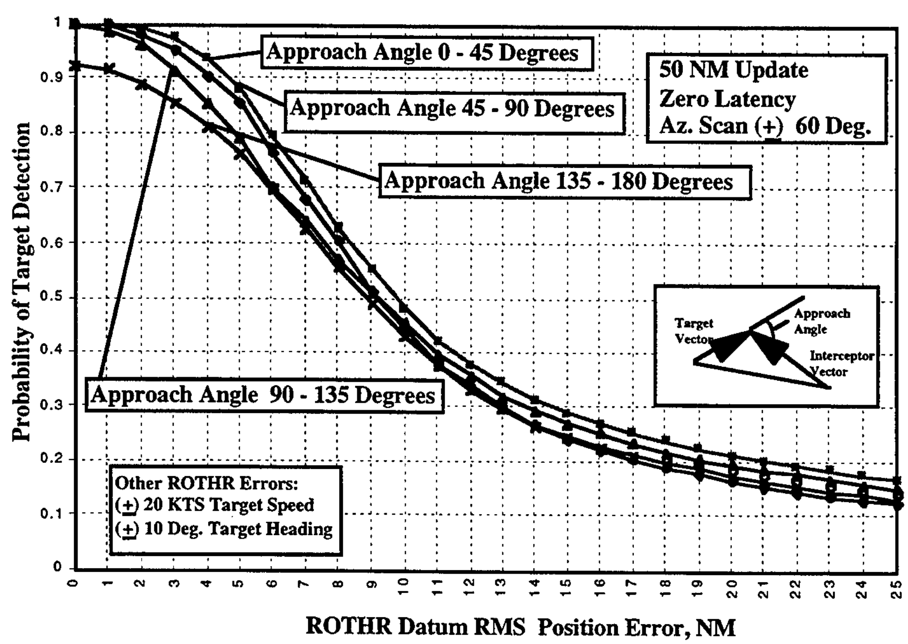

Figure 2.4.1. Detection Probability for Four Interceptor Approach Sectors with a 50 Datum and Zero Latency.

good results. This indicates, that if the interceptor has a real-time communications link to the ROTHR, stern sector intercepts are quite feasible. This has the effect of improving the end-game join-up on a target, lessening the chance of visual detection of the interceptor by the target, and reducing the chance of loss of radar contact during join-up maneuvering.

However, with the presently envisioned command and control infrastructure, ROTHR communications latency is expected to be of the order of 5 minutes at best. Figure 2.4.2 shows the impact this has on expected intercept performance for a 100 NM datum range. While the frontal approach sector still looks good, the beam-stern and stern approach sectors are significantly degraded.

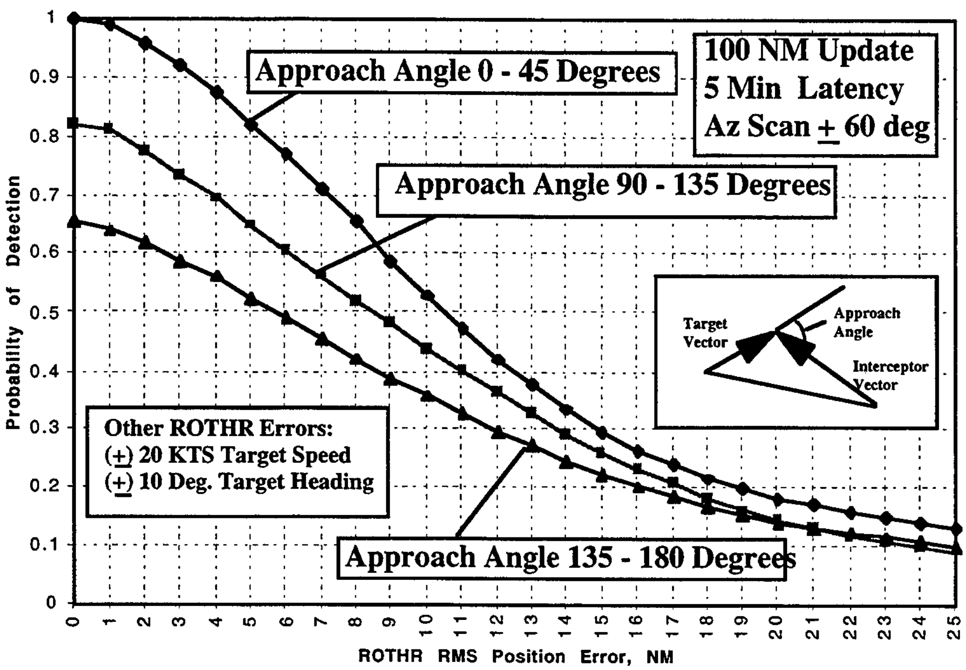

Figure 2.4.2. Detection Probability for Three Intercept Approach Sectors with a 100 NM Nominal Datum and a 5 Minute Compensated Latency.

Another issue relating to operational concept development is the effect of ROTHR datum range on the probability of intercept. Since the ROTHR datum will contain errors, it is of interest to investigate this relationship to determine whether there is an "optimum" datum range for a given intercept geometry. Figure 2.4.3 shows results of such analysis for three approach sectors - frontal, stern-beam, and stern. Latency is assumed to be 5 minutes, compensated and ROTHR position error is assumed to be 7 NM - values currently cited as operationally achievable.

The results indicate that there is actually a degradation in intercept probability if the datum is provided too close, in particular for frontal intercepts. Nominal datum of less than 70 NM for this case starts to degrade intercept performance, and similarly - though to a lesser degree - intercept probabilities decrease from a slightly closer datum range for the stern-beam and stern approach setups.

The reason for this phenomenon is the interaction of the inherent ROTHR datum errors and the latency, particularly in the near-frontal intercept case. Due to the 8 NM per minute closing speed, the actual distance between the target and the interceptor could be very small - near zero in some cases. The ROTHR position error inherent in the intercept solution can then be such, that the actual target position could actually be to the rear of the interceptor, or sufficiently far to either side of the interceptor radar sweep swath as to never be detected.

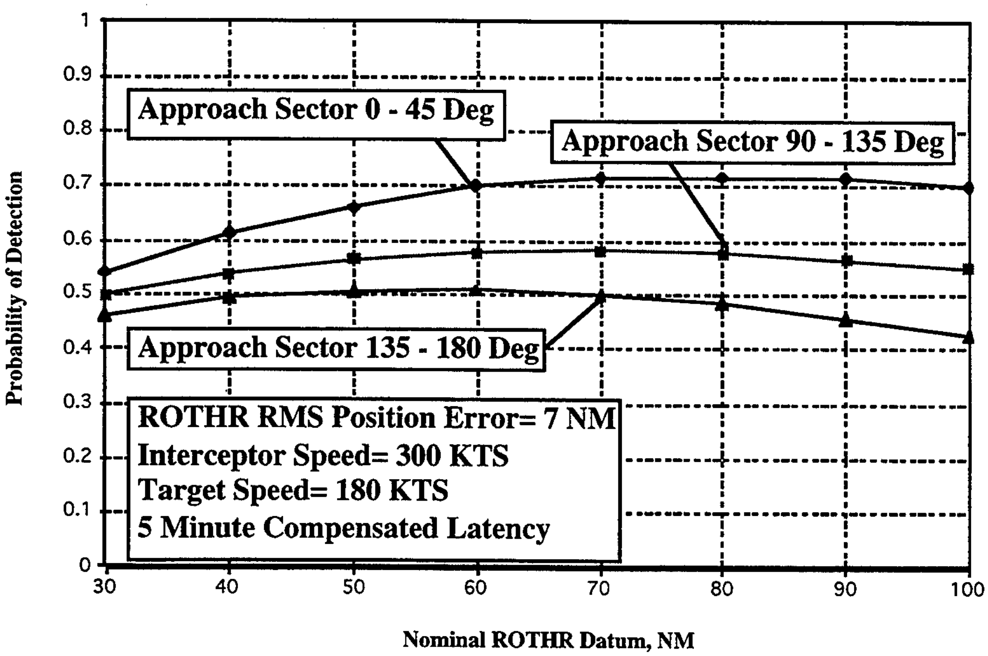

Figure 2.4.3. Target Detection Probability versus Datum Range for 7 NM ROTHR RMS Position Error and 5 Minute Compensated Latency.

2.5. Analysis of the Impact of Higher Target and Interceptor Speeds on Intercept Tactics.

The analyses described thus far have focused on a nominal 300 KTS speed for the interceptor and a nominal 180 KTS speed for the target. These represent reasonable values, representative of many target aircraft involved in drug trafficking, and a comfortable speed for the A-37B.

However, some twin engine aircraft encountered in drug interdiction can cruise at higher speeds, and the question of the impact on intercept success probability and the usefulness of higher interceptor speeds arose. This section describes the results of sensitivity analyses conducted to gain insight into the speed tradeoff issue.

Figure 2.5.1, Figure 2.5.2 and Figure 2.5.3 show results of intercepting a 220 KTS target with interceptors flying at 300 KTS, 350 KTS and 380 KTS respectively. All cases are for a compensated latency of 5 minutes and 50 NM nominal datum.

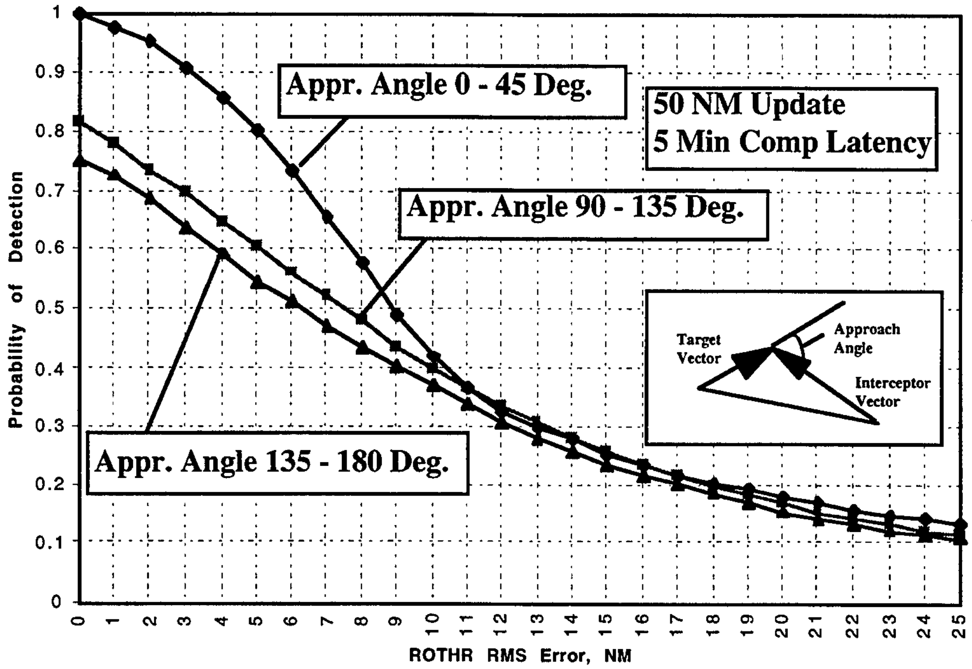

Figure 2.5.1. Target Detection Probability for Three Approach Sectors for a 220 KTS Target and 300 KTS Interceptor.

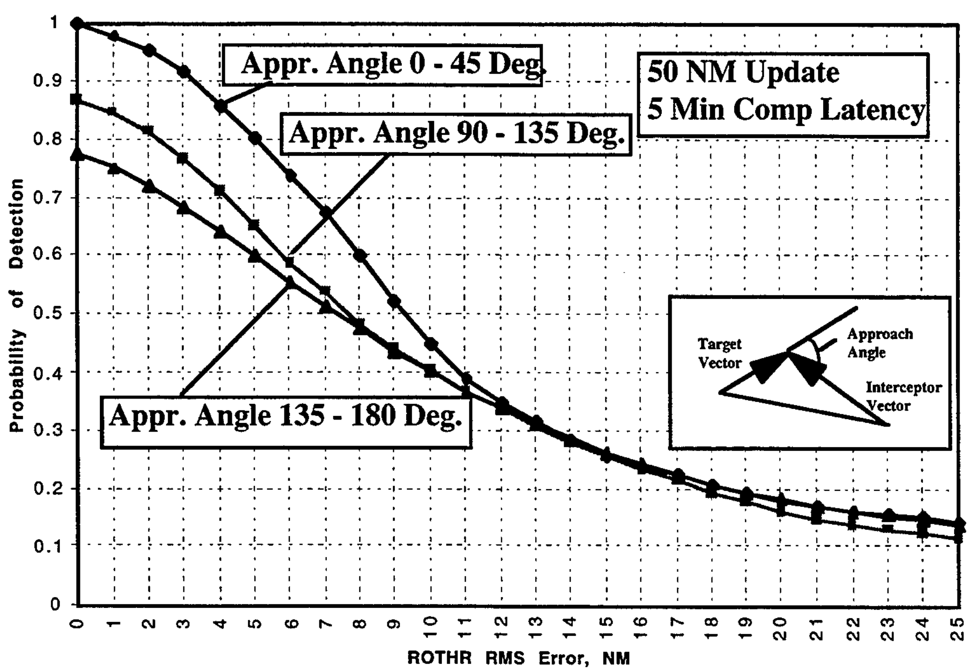

Figure 2.5.2. Target Detection Probability for Three Approach Sectors for a 220 KTS Target and 350 KTS Interceptor.

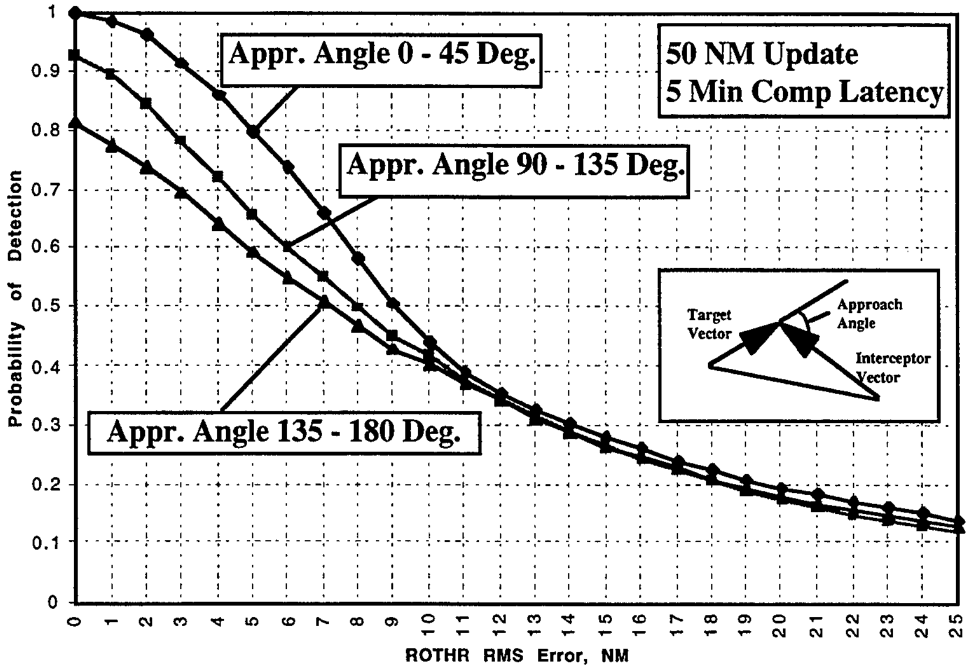

Figure 2.5.3. Target Detection Probability for Three Approach Sectors for a 220 KTS Target and 380 KTS Interceptor.

Comparison of the results shows that there is zero to very minor difference in target detection probability for any of the approach sectors over the interceptor speed range of 300 KTS to 380 KTS. Frontal approaches always look superior for ROTHR position error below about 10 NM, and stern sector approaches are only slightly improved by increasing interceptor speed from 300 to 350 KTS.

These results indicate that there is no benefit in the interceptor exceeding 350 KTS against targets flying at 220 KTS or less, and that there is only marginal improvement in increasing intercept speed from 300 KTS to 350 KTS. There is little advantage in interceptor speeds above 300 KTS against targets in the 180-220 knots category.

2.6. Analysis of ROTHR Performance Goals Impact.

The ROTHR program technical and operational community has established a set of future performance goals for the system, which include the following:

- Track position accuracy of $\pm$ 3 NM,
- Track heading accuracy within $\pm$ 5 degrees, and
- Track speed within 5 percent of true airspeed.

Analytical runs were made to obtain results that are reflective of such ROTHR performance, and are shown in Figure 2.6.1. The results are averaged over all aspects. However, it is seen from this chart, that intercept performance is excellent for reasonable datum ranges and latencies. Even a 5 minute **uncompensated** latency yields a respectable Pd of 70 percent from a 70 NM datum.

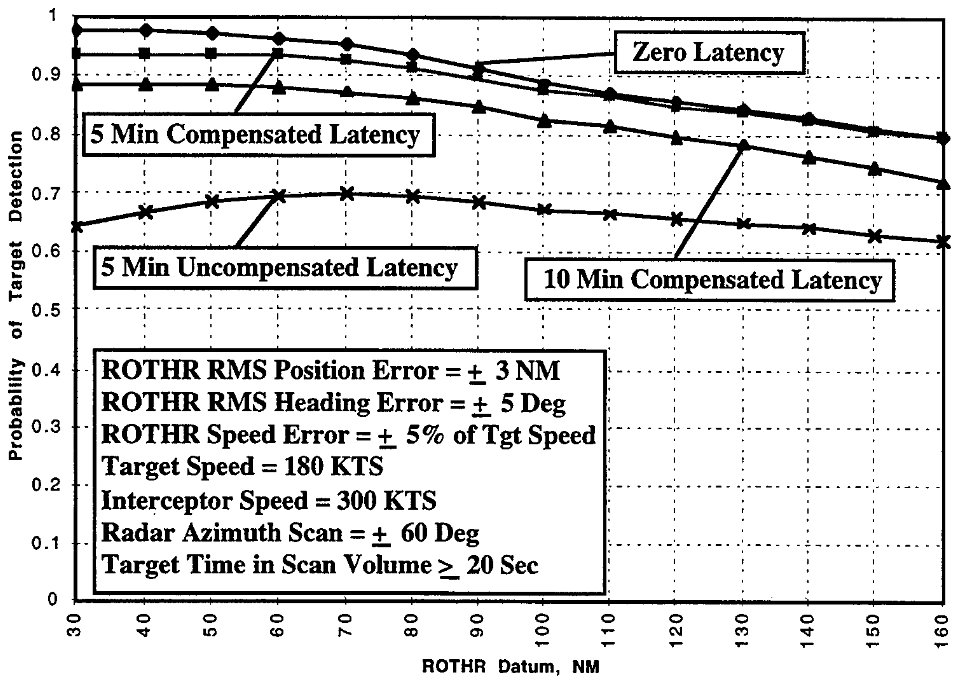

Figure 2.6.1. ROTHR Goal Performance Results.

2.7 Analysis of Interceptor Reach.

In a real-world environment, where geography shapes the operating environment of drug interdiction operations, operational issues such as locations of airfields, drug-traffic aircraft flight paths, destinations, climate, national boundaries and available interceptor bases enter into the overall issue.

Since the IDA model does not address interceptor range issues, a simple kinematic model was built to evaluate the range (or time) required for an interceptor with a constant speed to intercept a constant speed target detected at a given distance from the starting point (e.g. the interceptor's base) over the initial aspect angle spectrum ranging from a pure head-on intercept to a pure stern-chase. The model geometry is shown in Figure 2.7.1.

This analysis was guided by an assessment of the performance of the A-37B, derived from the performance charts presented in the A-37B Dash-One manual (T.O. 1A-37B-1). These indicate, for an A-37B taking off from a 1000 ft. MSL runway at a temperature of 95 degrees. F., with a two man crew, full internal fuel, full ammunition for the 7.62 mm. internal gun, four external fuel tanks, and two rocket pods (as an approximate drag count/weight surrogate for the APS-144 pod on the left wing and counterweight on the right), that its operational radius - allowing for take-off, climb to 15,000 feet, cruise at 300 KTS, return to base and 300 lb. landing fuel reserve - is about 250 nautical miles.

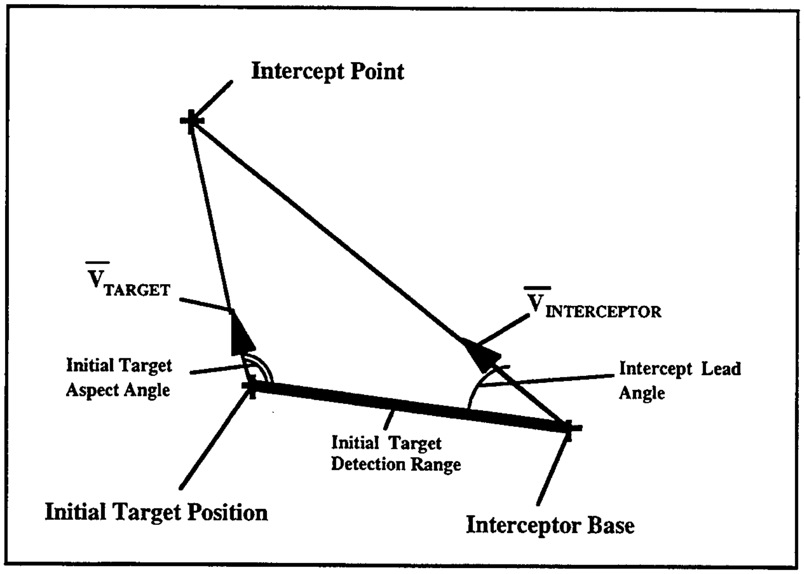

Figure 2.7.1. Model Geometry for Interceptor Reach Analysis.

Four cases were run, assuming a constant interceptor speed of 300 KTS, against targets in the speed range of interest. Case 1 assumes that the target is detected 100 NM from the base, Case 2 assumes 150 NM, Case 3 assumes 200 NM, and Case 4 assumes 400 NM offset. These are shown in Figure 2.7.2, Figure 2.7.3, Figure 2.7.4, and Figure 2.7.5 respectively.

Note that in all cases, the distance flown by the interceptor is shorter for higher speed targets when the geometry has a large "head-on" velocity component, whereas in the larger aspect angle cases, the reverse is true.

The 250 NM operational radius of the A-37B is drawn across each chart, to indicate the feasibility of the aircraft reaching each target over the entire range from head-on to stern-chase. It is seen , that only in the case of a 100 nautical mile target offset can the A-37B reach a target for any setup (Figure 2.7.2). At 150 NM offset, only the 115 KTS targets (Cessna 172, Piper PA-28 type) be fully reached, while the upper end 180 KTS targets (Cessna 310, Piper PA-34, Beach 55/58 type), are not reachable over a significant aspect range (Figure 2.7.3). For the 200 nautical mile offset the A-37B can only handle about the lower 50 percent of the aspect angle range (Figure 2.7.4).

Beyond 200 nautical miles offset, the A-37B rapidly becomes restricted to the frontal approach zone. This is also potentially the most likely intercept setup to result in loosing the target due to the high closure rates as discussed earlier.

Eventually, the combined performance of the interceptor and the targets makes intercepts infeasible for a given interceptor/target set. As seen in Figure 2.7.5, the 400 nautical mile offset is the limiting case here, where only the 180 KTS target can barely be intercepted by an A-37B at 300 KTS directly head-on. For the slower targets, the interceptor must turn

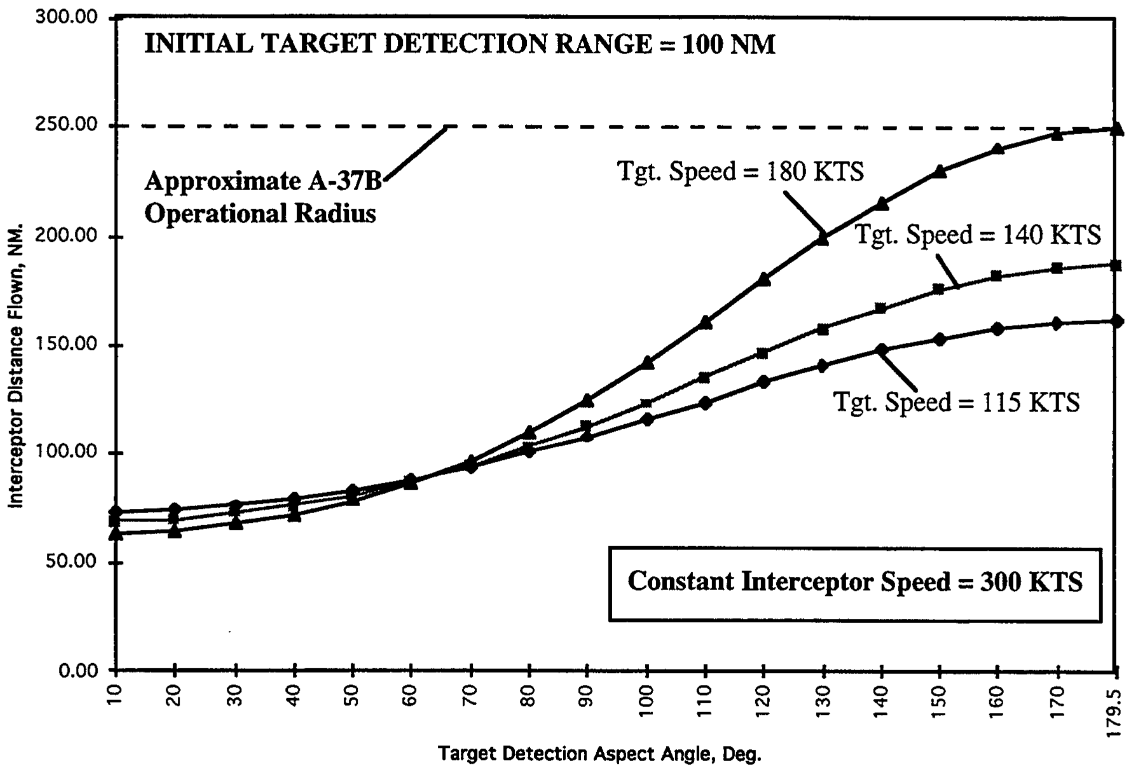

Figure 2.7.2. Interceptor Distance Flown vs. Target Aspect Angle - 100 NM Initial Range.

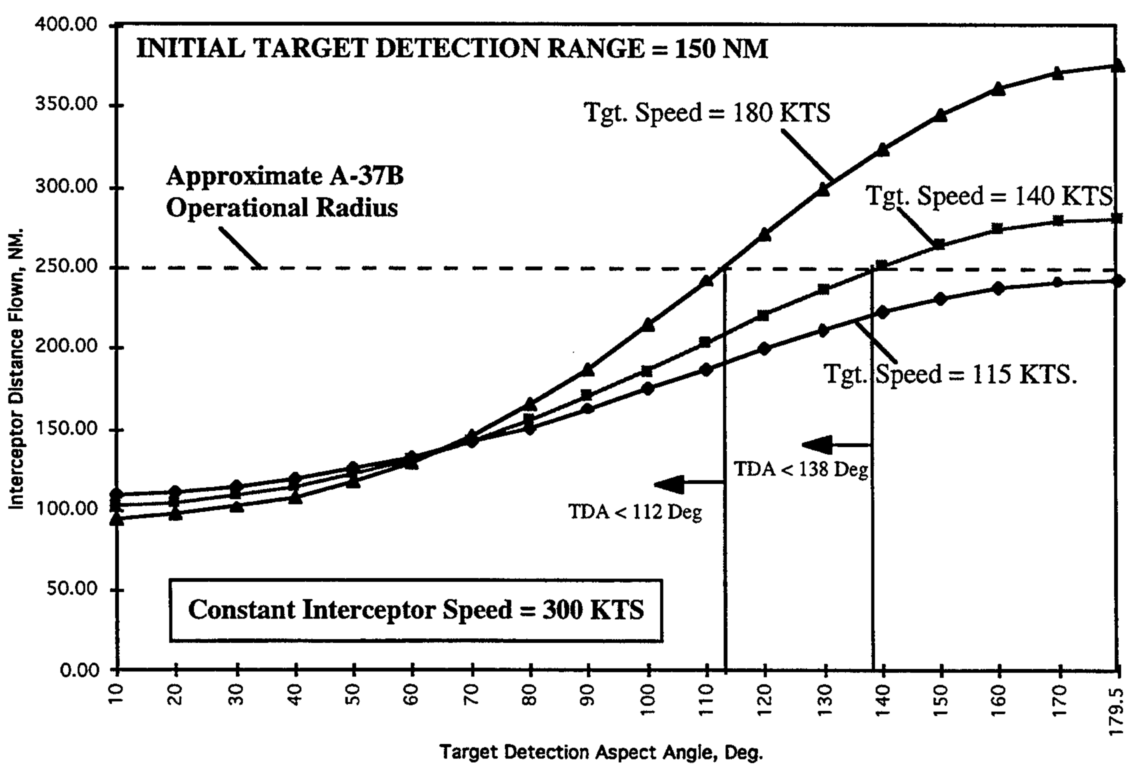

Figure 2.7.3. Interceptor Distance Flown vs. Target Aspect Angle - 150 NM Initial Range.

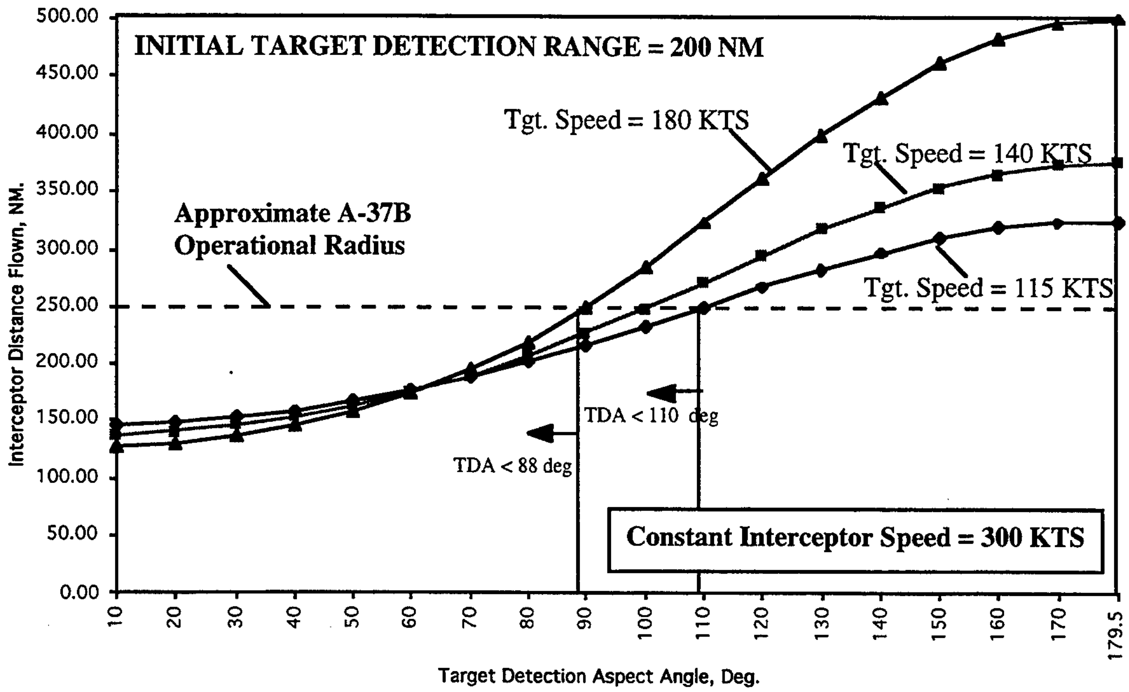

Figure 2.7.4. Interceptor Distance Flown vs. Target Aspect Angle - 200 NM Initial Range.

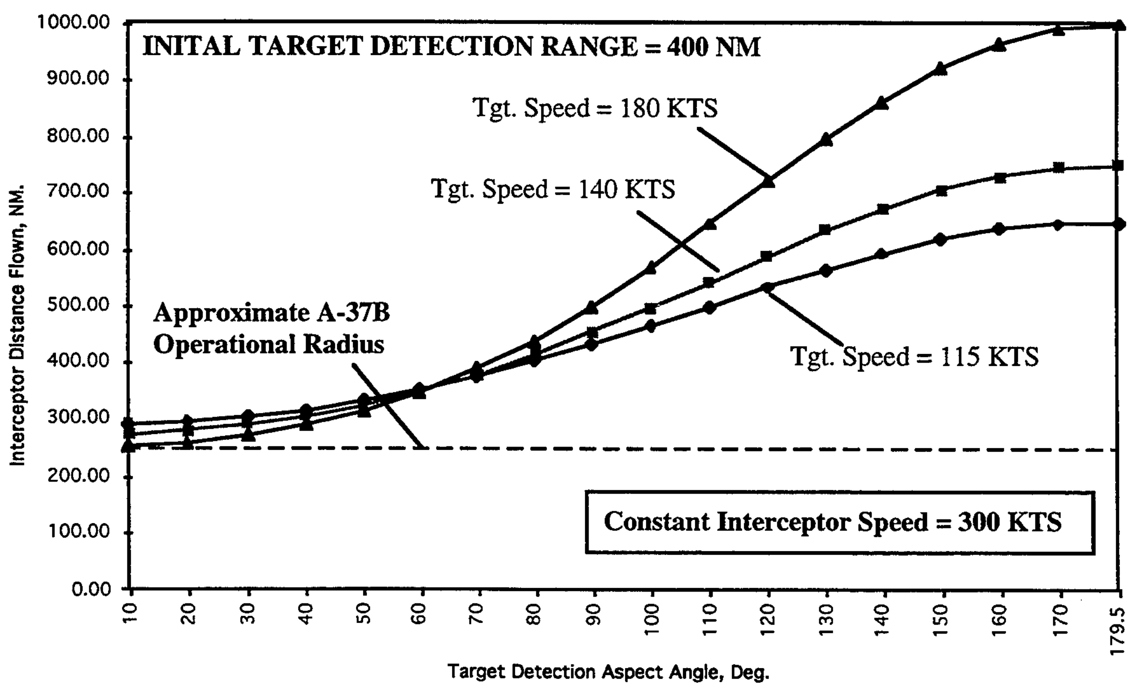

Figure 2.7.5. Interceptor Distance Flown vs. Target Aspect Angle - 400 NM Initial Range.

back before the targets reach its 250 nautical mile operational radius limit. Of course it may be operationally feasible for the interceptor to return to another base that is closer to the intercept point to extend its effective reach and/or time with the target.

3.0 End-Game Analysis.

The objective of a typical drug aircraft interdiction mission is to intercept the suspect aircraft, identify it, force it to land, apprehend the crew and confiscate the cargo. Therefore, the interceptor needs to join up with the target, as opposed to shooting it down in a traditional collision course intercept mode. This imposes some constraints on the manner in which the "end-game" has to be exercised.

The models used in the preceding analyses are not suitable for addressing the final phase of a counterdrug air interdiction mission, since they do not include the necessary features for handling the end-game dynamics and decision logic.

As has been indicated previously, the most stressful end-game scenario is the head-on or near-head-on intercept. The relatively short range of the AN/APS-144 radar and the inherent errors in the ROTHR-based intercept solution mean that when the interceptor makes radar contact with a target, there is very limited time (approximately two minutes) available to "set up" the intercept. Figure 3.1 shows an example of an "ideal" head-on intercept. The interceptor is positioned such that it can execute a well-timed join-up turn from an offset head-on approach in such a manner that it maintains radar contact with the target all the way. This type of intercept could be set up either by an intercept controller who has precise relative tracks on both the target and the interceptor well in advance, or by the interceptor crew if they acquire the target at a sufficient range to set up the desired intercept geometry.

The situation depicted in Figure 3.1 assumes that the interceptor has approximately a 20 percent speed advantage over the target, which in the case of a 180 KTS target means about 216 KTS.

Figure 3.2 shows a "beam" intercept with similar relative speed conditions. Again, this intercept would be set up with sufficient lead time to provide the interceptor with sufficient time to set up for this intercept. Again, radar contact can be maintained throughout the join-up maneuver.

Figure 3.3 shows the most benign intercept setup, a stern intercept, whereby the interceptor approaches from a stern aspect, and uses speed control and gentle maneuvering to join up on the target from behind.

In the case of the podded radar intercepts cued by ROTHR these may not always be feasible. If a time-constrained frontal approach join-up is forced upon the interceptor, the situation depicted in Figure 3.4 may be representative of the situation encountered. Here, the interceptor does not have time to set up for an offset head-on end-game, and hence must execute a track crossing maneuver, followed by a turn back to re-acquire the target on radar and close in from the stern.

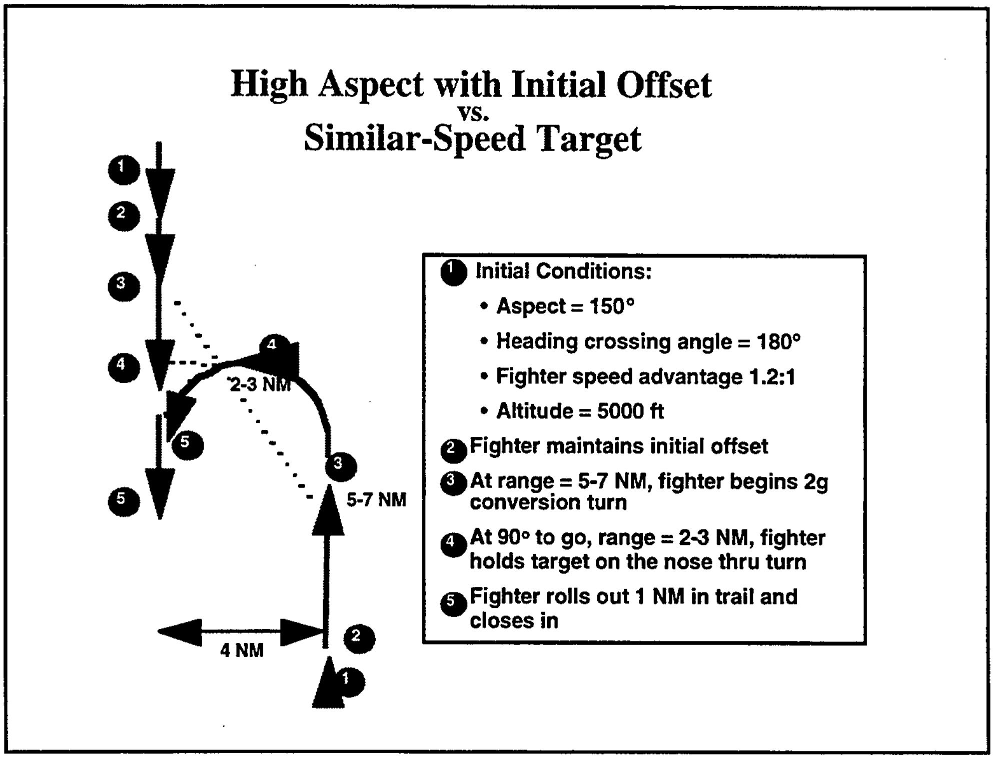

Figure 3.1. An Ideal Head-On Intercept.

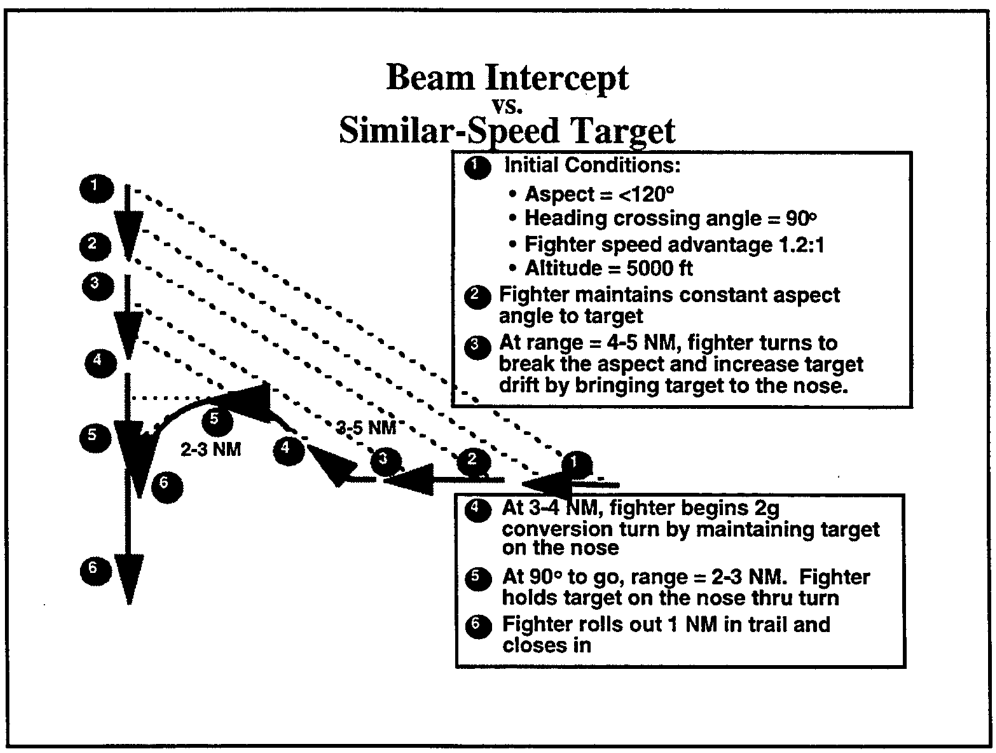

Figure 3.2. An Ideal Beam Intercept.

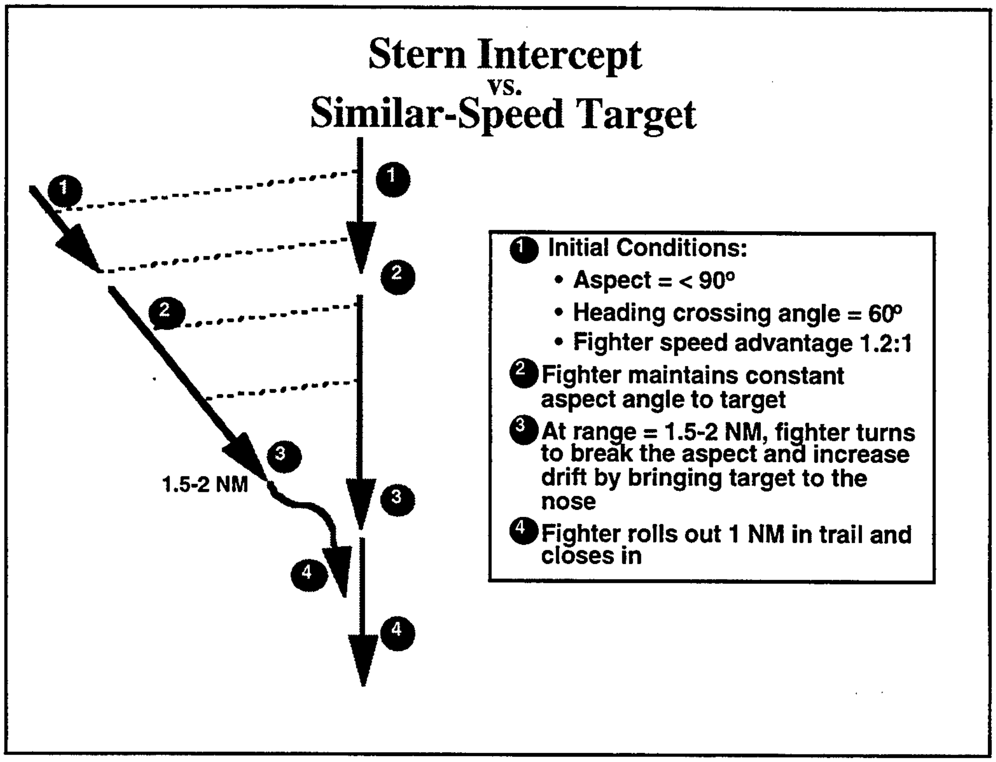

Figure 3.3. An Ideal Stern Intercept.

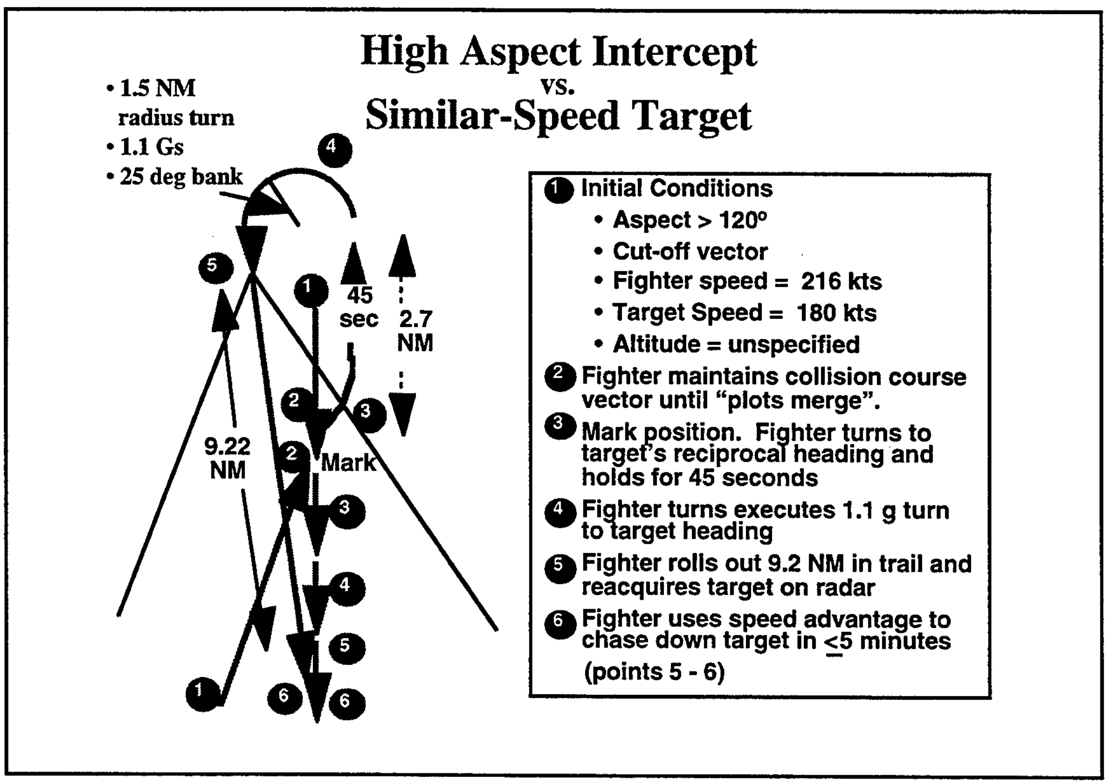

Figure 3.4. A High Aspect Intercept.

This example shows a setup whereby the interceptor pilot "marks" the track crossover point, flies a reverse heading for 45 seconds to open up the range (2.7 NM) prior to turn back to the target's track. The turn is assumed to be a 1.1 G turn, which at 216 KTS implies a 25 degree bank. As the interceptor rolls out of the turn, it is a little over 9 NM behind the target. At that range, the podded radar has a field of view that allows it to detect the target even if it had turned $\pm$ 30 from its initial heading at the crossover point. At the assumed speed of 216 KTS and target speed of 180 KTS the interceptor closes on the target within 5 minutes. However, if the target changes course by more than 30 degrees, it may not be immediately in the field of view of the radar after the turn, and may escape re-acquisition.

A theoretical frontal aspect end game scenario was developed, wherein the interceptor can maintain radar contact throughout its join-up maneuver. This is shown in Figure 3.5. In this case, the interceptor is assumed to be properly set up on a beam-frontal collision course, and has established radar contact. At 1 minute prior to commencing the join up turn, the slant range is 8.3 NM. At the start of the turn, the slant range is 2.75 NM, and the target is slightly right off the nose of the interceptor. The interceptor starts a coordinated 25 degree bank turn (1.1G) and turns through an arc of 130 degrees in 58

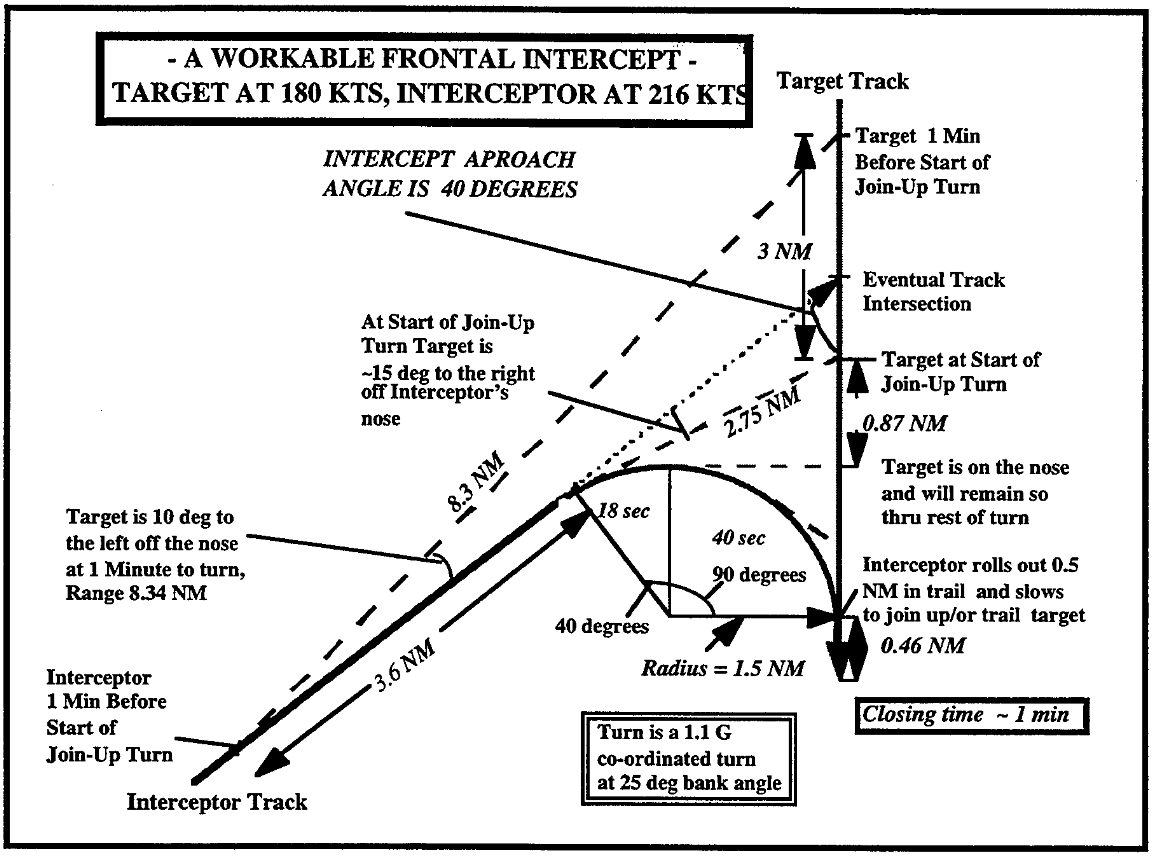

Figure 3.5. A Join-Up Maneuver with Continuous Radar Contact.

seconds. As the turn proceeds, the target moves to the nose-on position, and remains there. At the end of the turn, the interceptor is a little less than a half mile in trail, and can join up on the target in about 1 minute.

While this example demonstrates a workable case of converting from a frontal beam encounter to target join-up, this situation is very time critical, and in many cases will not be achievable in the ROTHR/APS-144 radar intercept process. The less stressful beam or stern intercept scenario is obviously desirable, but the tactical situation may dictate use of frontal sector approaches.

4.0 Riverine Operations Analysis.

As previously stated, the AN/APS-144 radar can also perform air-to-ground detection of moving objects, such a boats on the surface of rivers, as well as vehicles on the ground.

In order to provide initial insight into the operational feasibility of using the APS-144 to detect riverine traffic, an analysis of river visibility from the air was undertaken. Four river segments in South America were selected for analysis. The rivers involved are the Huallaga River in the Peruvian Amazon region; the Putumayo on the Peru-Columbia border; and the Guaviare and Vichada in Columbia. Their locations are shown in Figure 4.1.

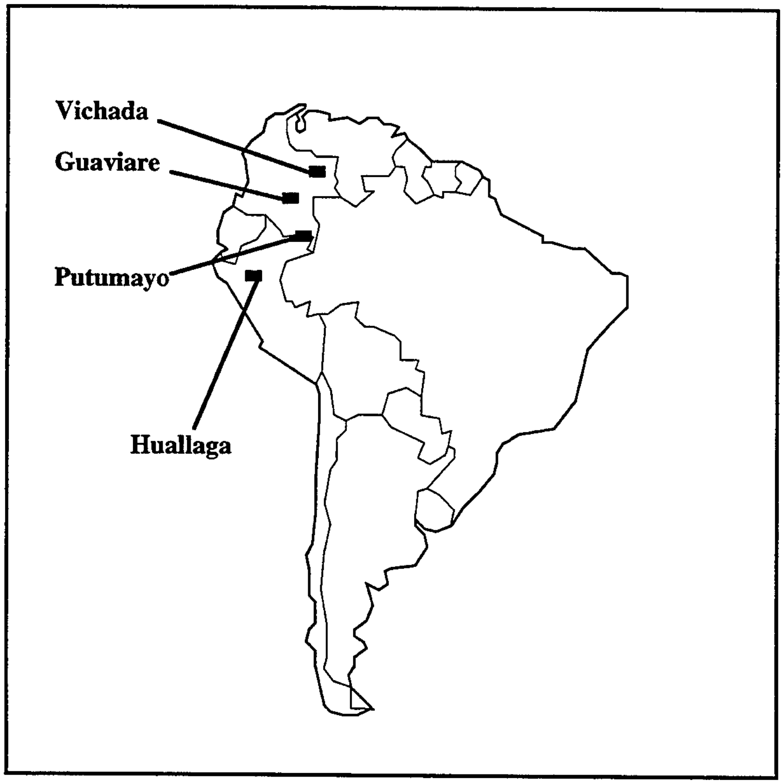

Figure 4.1. Location of the Four River Segments in South America.

A Geographic Information System (GIS) tool called "VISIBILITY" was used to simulate the viewing of the rivers from flight profiles at 2000 and 5000 feet using look-down angles of 10, 30 and 40 degrees (the latter is the maximum lookdown angle achievable by the APS-144). An azimuth scan sector of $\pm$ 30 degrees was used, centered along the direction of travel. Two types of trajectories were analyzed - straight line, where the path was chosen to maximize the achieved coverage, and an approximate "river following" trajectory, which assumes that an aircraft attempts to match the bending of the river within reasonable aircraft turn, bank and G limits.

The analysis was conducted utilizing the Defense Mapping Agency's Digital Chart of the World data base. Accurate geographic elevation data was not readily available for the areas of interest. However, review of aerial maps of the chosen geographic areas shows the terrain to be quite flat, so terrain elevation was taken as zero for each region. Reports from in-theater sources indicated that tall dense trees generally grow to the river edge. It was therefore assumed that the jungle forms an opaque, uniform "wall" of trees down to the river's edge. Tree height was assumed 100 feet. While an approximation, this is also a "worst case" for visibility analysis, and hence the results are conservative.

Two types of analysis were run, the first computing the total visible surface area of each river segment during each pass, the other computing the total river bank length visible during each pass. The latter was generated to gain insight into the possibility that a boat could be steered up to the bank on the sound of an approaching aircraft.

Figures 4.2 through 4.5 show each of the river segments in more detail.

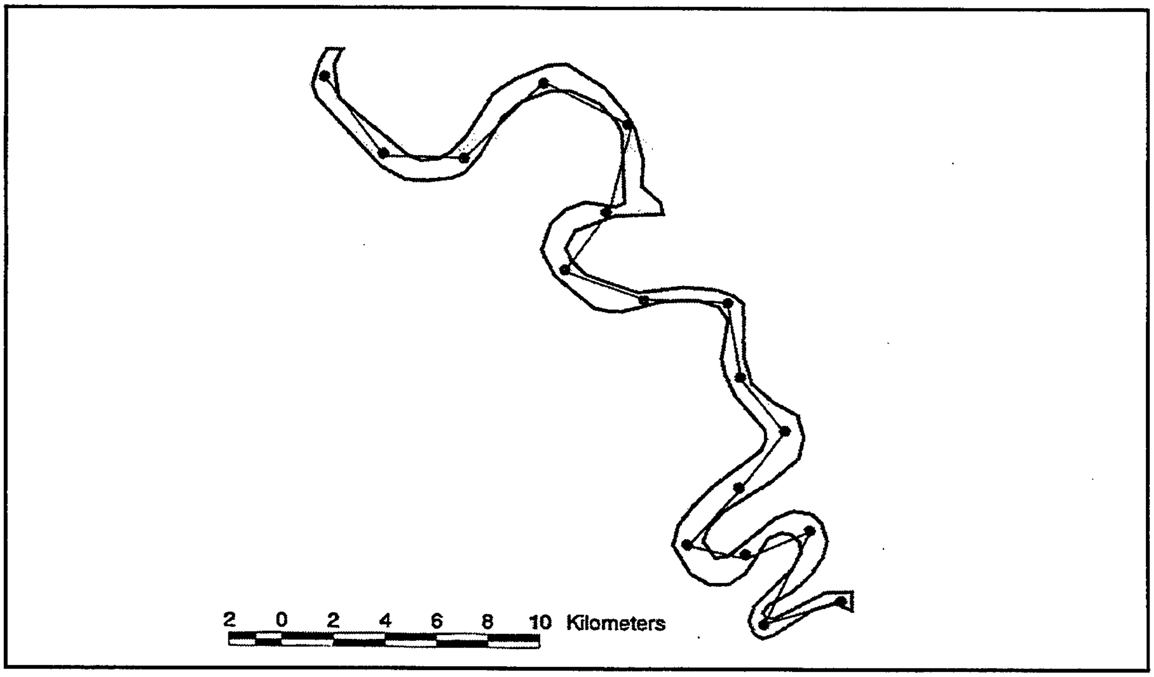

Figure 4.2. Huallaga River Segment Used for Riverine Visibility Analysis.

The line segments overlaid on the river maps are the trajectories used for the "river following" mode.

The results of the visibility analysis for area coverage are summarized in Table 4.1 to Table 4.4, and those for riverbank coverage in Table 4.5 through Table 4.8.

As can be expected, the higher altitude, river following and greater lookdown angles give the best results. The tabulations show, that in general, that the river following flight paths

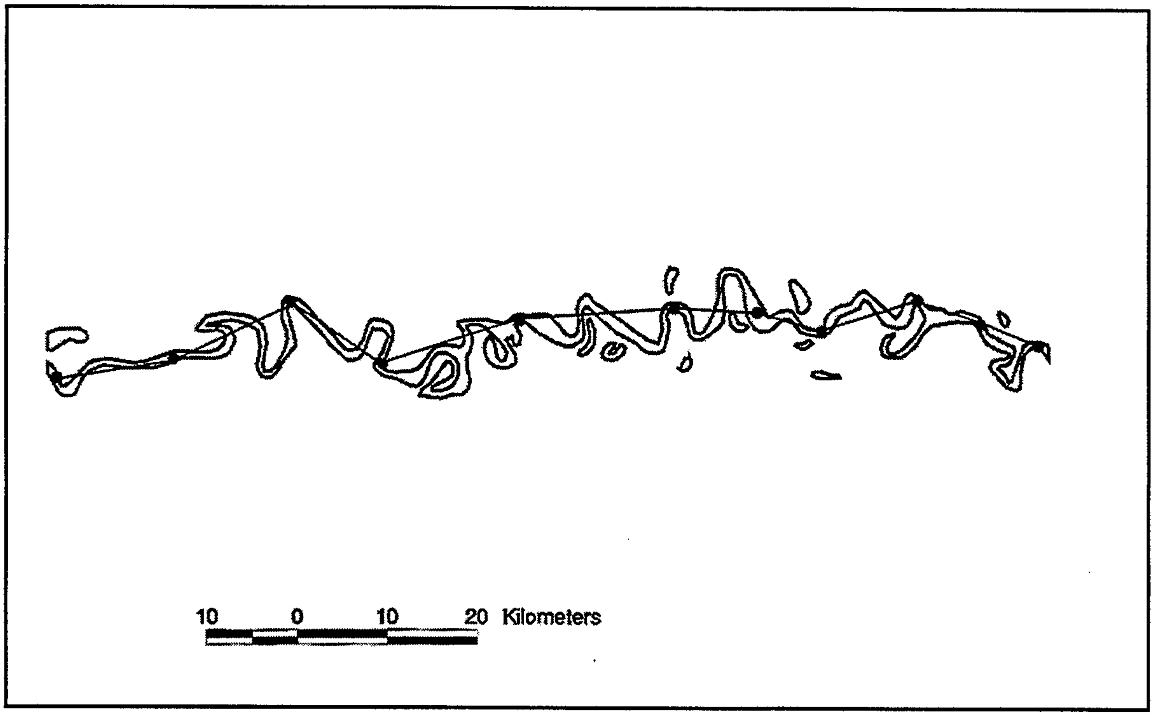

Figure 4.3. Guaviare River Segment Used for Riverine Visibility Analysis.

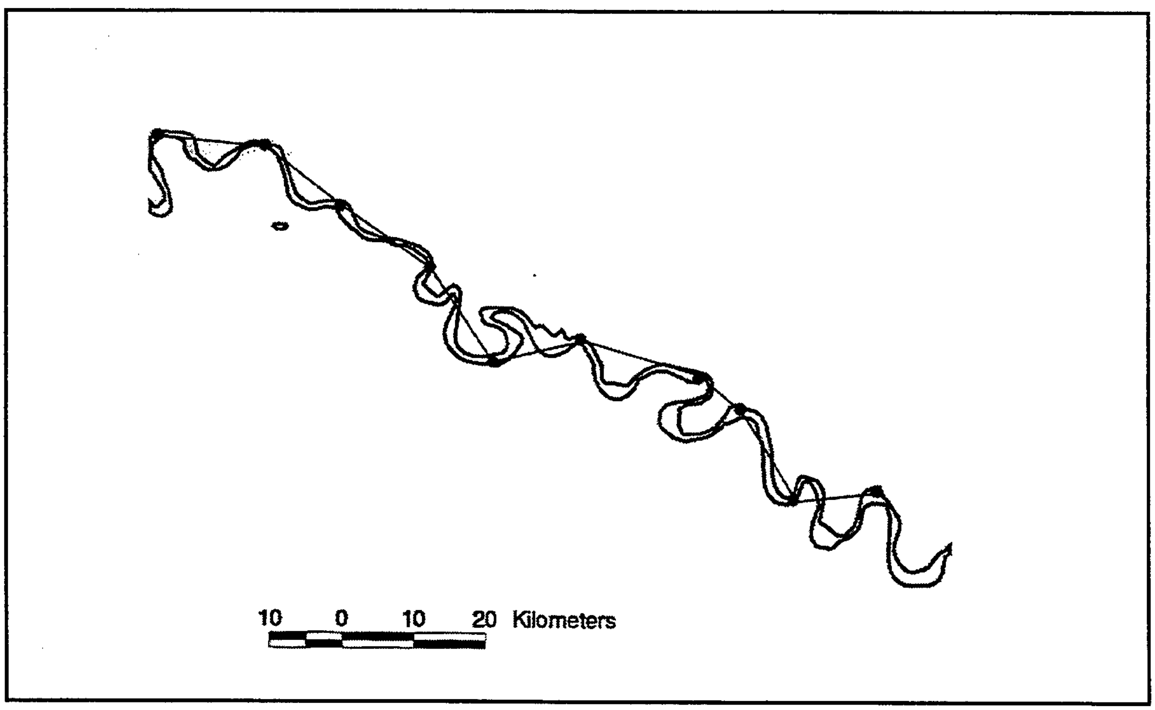

Figure 4.4. Putumayo River Segment Used for Riverine Visibility Analysis.

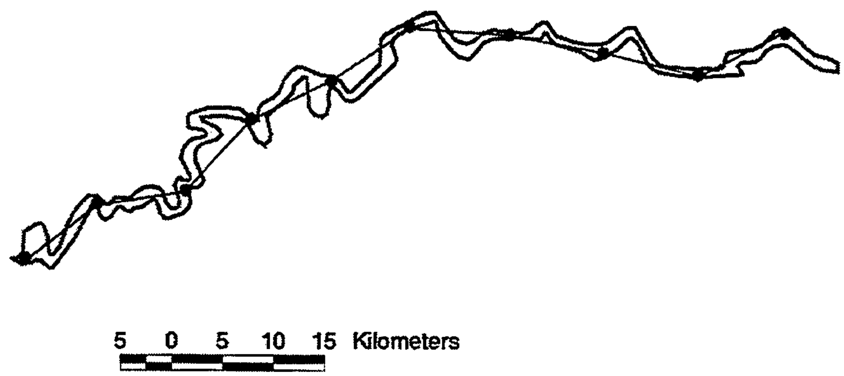

Figure 4.5. Vichada River Segment Used for Riverine Visibility Analysis.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	15.55	31.68	22.03	44.88
30	12.04	24.53	8.21	16.72
40	12.00	24.44	6.87	13.99
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	11.63	23.69	21.64	44.08
30	6.27	12.77	5.48	11.16
40	6.17	12.57	3.53	7.19
TOTAL AREA EXAMINED (km^2): 49.09 - Huallaga				

Table 4.1. Area Coverage of Huallaga River Segment.

flown at an altitude of 5000 ft AGL, result in well over 80 percent of both the river area and riverbank being visible. It is of interest to note, that the Guaviare river following results are slightly inferior to the constant heading case. The reason is that the combination of the river geometry and the approximate "river following" path used in this particular case is not optimum, and the straight line path actually represents a better profile. This suggests that operational river surveillance missions need to be carefully planned to yield the best results.

The river following flight paths used here generally would not involve very extensive maneuvers, and in practice each river could probably be followed more closely, with an

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	76.77	35.26	48.56	22.30
30	71.68	32.92	31.43	14.43
40	70.96	32.59	30.88	14.18
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	86.59	39.77	54.13	24.88
30	82.04	37.68	36.27	16.66
40	81.78	37.56	34.94	16.05
TOTAL AREA EXAMINED (km^2): 217.74 - Guaviare				

Table 4.2. Area Coverage of Guaviare River Segment.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	88.33	36.92	57.86	24.19
30	84.11	35.16	43.83	18.32
40	83.67	34.97	43.42	18.15
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	86.43	36.15	54.98	22.98
30	79.51	33.24	39.48	16.50
40	79.12	33.07	37.99	15.88
TOTAL AREA EXAMINED (km^2): 239.23 - Putumayo				

Table 4.3. Area Coverage of Putumayo River Segment.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	44.31	35.56	32.20	26.57
30	43.35	35.77	28.95	23.89
40	43.35	35.77	28.79	23.76
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Area Masked (km^2)	Percent Masked	Area Masked (km^2)	Percent Masked
10	32.92	27.16	26.66	22.00
30	26.37	21.76	15.78	13.02
40	25.90	21.37	13.91	11.48
TOTAL AREA EXAMINED (km^2): 121.19 - Vichada				

Table 4.4. Area Coverage of Vichada River Segment.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	33.0	31.91	45.3	43.81
30	29.5	28.53	16.2	15.67
40	28.7	27.76	16.2	15.67
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	30.9	29.88	45.2	43.71
30	24.7	23.89	3.7	3.58
40	24.6	23.79	1.2	1.16
TOTAL RIVERBANK EXAMINED (km): 103.4 - Huallaga				

Table 4.5. Riverbank Coverage of Huallaga River Segment.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	122.4	25.05	111.9	22.90
30	118.2	24.19	82.6	16.91
40	117.9	24.13	80.8	16.54
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	129.4	26.48	115.4	23.62
30	125.4	25.67	88.6	18.13
40	125.0	25.58	87.1	17.83
TOTAL RIVERBANK EXAMINED (km): 488.6 - Guaviare				

Table 4.6. Riverbank Coverage of Guaviare River Segment.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	134.7	32.61	121.6	29.44
30	131.7	31.88	99.0	23.97
40	130.6	31.61	97.7	23.65
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	126.8	30.69	112.6	27.26
30	118.6	28.71	86.1	20.84
40	117.9	28.54	88.4	20.19
TOTAL RIVERBANK EXAMINED (km): 413.10 - Putumayo				

Table 4.7. Riverbank Coverage of Putumayo River Segment.

CONSTANT HEADING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	76.1	33.25	66.7	29.14
30	74.5	32.55	60.1	26.26
40	74.6	32.59	59.5	25.99
RIVER FOLLOWING				
	Altitude 2000 ft		Altitude 5000 ft	
Lookdown Angle (deg.)	Length Masked (km)	Percent Masked	Length Masked (km)	Percent Masked
10	56.6	24.73	58.0	25.34
30	51.4	22.46	35.3	15.42
40	50.8	22.19	33.0	14.42
TOTAL RIVERBANK EXAMINED (km): 228.9 - Vichada				

Table 4.8. Riverbank Coverage of Vichada River Segment.

expected increase in visibility beyond these results.

The Huallaga River segment is representative of the maneuvering required of an aircraft flying a true "river following" profile. Figure 4.6 shows the maneuvering requirements involved in following this particular segment. In spite of the snaking river, an aircraft flying at 170 KTS should not have difficulty in following it, and G-loads and bank angles are generally reasonable.

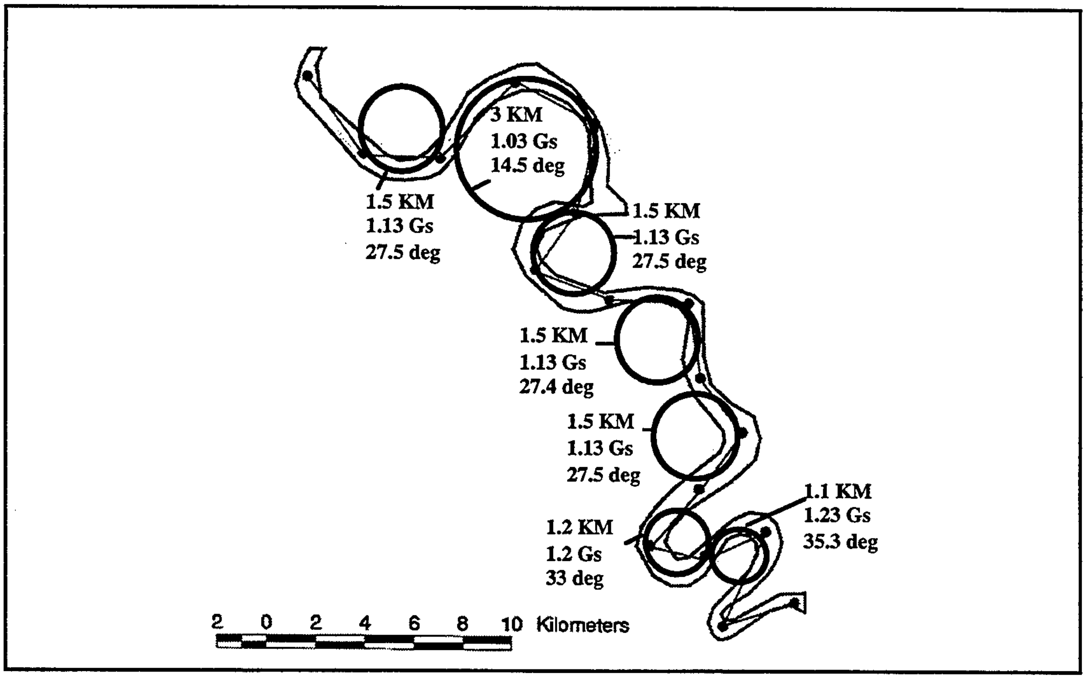

Figure 4.6. Turn Radii, G-forces and Bank Angles for Following Huallaga River Segment.