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Flight Planning Tool: An Aid for Efficient Flight Evaluation

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ABSTRACT

Airborne surveillance systems have multiple sensors and communication links on board a suitable platform. They work in a cohesive manner to provide effective surveillance over the region of interest. The performance proving of such a system is challenging and requires flight trails extending over years. The test results often have to be interpreted using statistical analysis of the flight test data. An efficient way is to carefully design the flight test profiles such that enough samples can be collected during the test and multiple requirements can be tested in a single sortie. Such meticulous test strategies where both own ship platform and test targets are moving with high dynamics call for software based tool for planning of test sorties and the test points.

Flight Planning Tool (FPT) plays an important role in pre-flight stage during developmental trials for analysis of the MOEs and MOPs of overall system and of various on-board sensors of an airborne multi-sensor system. The FPT provides statistical & graphical analysis for sensor behaviour for various scenarios (flight trials) before actual flight test is conducted. It provides prior information on number of valid samples for sensor testing during flight trials. In addition, the tool aids in assessing number of profiles to be flown for proving each MOE. The profiles can also be optimised such that valid samples are collected for evaluation.

Keywords: FPT; Primary Radar (PR); Identification of Friends & Foe (IFF); CSM; ESM

1. INTRODUCTION

Any airborne multi-sensor evaluation calls for extensive flight testing for design, fine tuning and performance proving. As per the system engineering practices flight test cards are prepared from the requirement database. A flight test card collates all those requirements that can be evaluated in a single test point and those uses same own ship and test target profiles. An important aspect dictating the number of tests that can be carried out in a single sortie is the number of "good" samples that can be collected where the sample quality is decided by the test under consideration. This calls for efficient planning of the own ship and test target profiles such that the data collected can be used for evaluation of the Measures of Performance (MOPs). Examples of MOP's include detection range, localisation accuracy, range resolution and azimuth resolution etc. Such precise flight planning requires software based tools that can run the flight profiles in a simulated environment and predict the sensor samples that can be collected along with the MOPs. The MOP's are subsequently aggregated, possible for multiple sensor, for evaluation of measures of effectiveness (MOE). Examples of MOE's are early warning time, target acquisition range, etc. Flight Planning Tool (FPT) described in this paper elucidates the features of such a tool. The FPT iteratively computes the best profiles for a sortie enhancing sensor sample collection and thereby reducing the overall flight test life-cycle. Such a flight planning tool is developed which facilitates definition of ownship airborne platform along with a test target trajectories. Based on this definition the tool analyses the samples collected for various parameters like sensor coverage, probability of detection, error analysis, etc. Based on the optimisation criteria for number of samples collected, the sortie profiles are iteratively changed to converge towards the goal. Then, the samples are collected and statistically analysed for deriving the MOP's for each sensor. The relevant MOP's are aggregated to compute the MOE's of the systems.

References[1-6] address optimisation of flight geometries from a fighter survivability or network wide civil flights view point. However, this paper considers joint optimisation of the own ship and target flight paths from a sensor test and evaluation viewpoint. Over the past years flight mission planning is one of the key technologies of aircraft system. The work by Mariusz Pakowski[1] described their own experience in the field of radar testing with the use of military aircrafts. Other work by Charles A. Leavitt[2] described real-time in-flight mission, tactical, and sensor planning system for conventional low-level aircraft. Maritime surveillance radar, simulation of flight trajectories and radar detection was described in[7,10,11-12] for airborne radar. William A. Skillman[8] described environmental effects on airborne radar performance. On the other hand, Luke Rosenberg[16] described the key trade-offs in designing a scanning maritime radar with details of how the radar return can be simulated.

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As seen from the above literature, none of these above works addresses an end to end tool for flight plan in dynamic airborne scenarios. They also fail to address the multi sensor detection scenario. This paper provides the design of input of a FPT in multi sensor airborne dynamic environment. The sensors are mounted on an airborne platform. The evaluation of MOP's of the sensors along with their aggregation by using an optimised flight test profile is challenging and required software based tools. The sensors considered are Primary Radar (PR), Identification of Friend or Foe (IFF), Electronic Support Measures (ESM), Communication Support Measures (CSM).

The FPT is built around a powerful scenario generation tool. FPT takes in the geometry of flight trials (own ship and targets), the sensor operational philosophy (test point time, sector, sensor setting) and predicts the expected sensor output. The tool is designed such that it displays all the flight test results as view graphs and statistics (e.g., how many radar plots are computed in an angular sector for probability of detection evaluation). The inputs to the tool are the flight path data of the own ship aircraft and of the test targets (aircraft, ships, static assets, etc.). As the simulation progresses, from the sequence of locations of both the sensor and the test target, FPT predicts different sensor characteristics like detection range; samples available based on sensor update, target coverage etc. After an iterative process, the FPT provides the flight profiles of own ship and targets for flight evaluation as output.

Flight geometries are often challenging in dynamic scenarios. For example, if one wants to evaluate the probability of detection performance along bore sight of an airborne active phased array antenna, then the speed and heading of both the own ship and test targets has to be carefully controlled as the target moves along the ranges of interest. Such scenarios require complex planning on the ground so that the profile can be executed in air with tolerable margins. The tool can also be used for exploring new test strategies for complex profiles. The tool can be used for any sensor system. For brevity sake, in this paper the tool will be described in terms of flight testing the parameters of active phased array airborne radar.

2. OVERVIEW OF FLIGHT PLANNING TOOL

The primary objective of FPT is to plan the own ship trajectory along with test targets so that enough samples can be collected meeting the test objectives. Also multiple requirements can be tested in a single sortie. The FPT has a modular architecture and has two core modules-Scenario Generation and Sensor Analysis. The architecture of the tool is as shown in Fig. 1.

The flight profiles of own ship and the test targets are generated in the scenario generation tool. The tool is capable of generation of multiple way points and motion profiles along these waypoints. The sensor analysis module simulates the sensor detections for the chosen flight geometry and sensor setting. The test outputs are checked if enough samples are obtained. Else the flight parameters of the own ship and the target are tuned in an iterative manner to ensure that enough samples are collected for evaluation of MOPs. Once iterations are completed the tool outputs the flight profiles that can be tested in actual. The modules of the tool are described in the following sections.

2.1 Scenario Generation

Scenario Generator (SG) is a software that is used to build a tactical database and then simulate dynamic, interactive, complex, and real-time tactical and operational environments. These environments, called scenarios, contain individual platforms (such as fighter planes, ships, trucks, radar sites, etc.) that interact through detection, communication, engagement and/or destruction. Platforms may be equipped with weapons, such as guns, artillery, and missiles, and other defining characteristics. It is developed using commercial software called 'STAGE' as a backend[23]. The software provides features for planning the scenario with multiple entities and running these according to the plan. A typical example of the scenario is shown in Fig. 2, which shows a race course profile for the ownship and profiles for different targets.

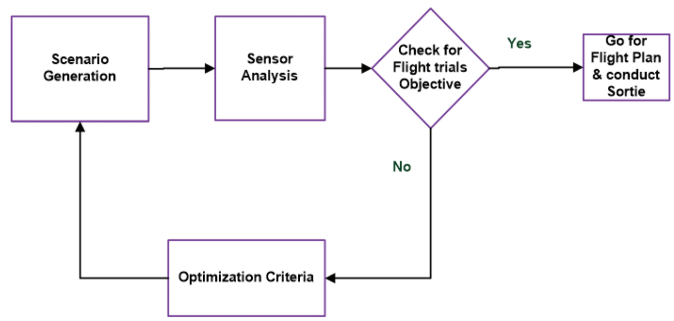


Figure 1. Architecture of flight planning tool.

2.2 Sensor Analysis

The sensors simulator receives the own ship and target parameters from (SG). The scenario generator and the sensor analysis is time synchronised. The simulation models of the various sensors are populated based on the performance characteristics of the actual units under airborne test. These sensor models[20-22] have been built around a modular architecture where in the core physics based module that mimics the sensor behaviour is separated from the parameters that control the model and various interface definitions. The sensor outputs can be sent over Ethernet for analysis or recorded. Modular architecture of the sensor models along with interface with scenario generator and sensor output analysis system is shown in Fig. 3. The simulation models are populated for Primary

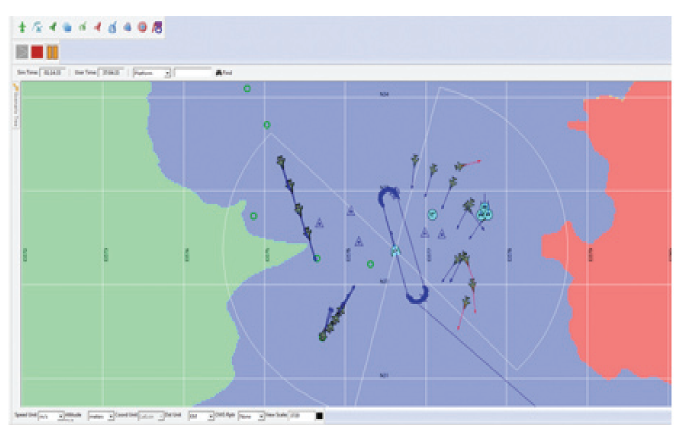


Figure 2. Scenario with targets along with ownship.

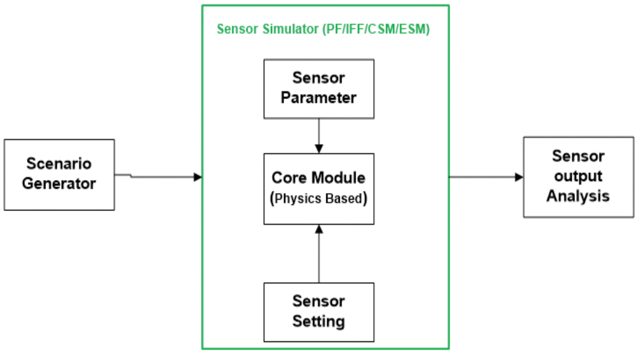


Figure 3. Modular architecture of sensor model.

Radar (PR), Identification Friend or Foe (IFF), Electronic Support Measure (ESM) and Communication Support Measure (CSM). The detected target reports like Radar & IFF plots, ESM emitter reports, CSM emitter reports are sent to the analysis station for display purpose or recorded for automated analysis.

2.3 Flight Trials Objective

The objective of the flight trial is collection of sufficient samples such that statistical qualities defined in the MOPs can be evaluated. The aggregation of MOP's results in MOE's. The objectives of each flight sortie is different. Example objectives are computing probabilities, computation of error between measured and actual parameters, computing resolution between different targets, sensor coverage etc.

2.4 Optimisation Criteria

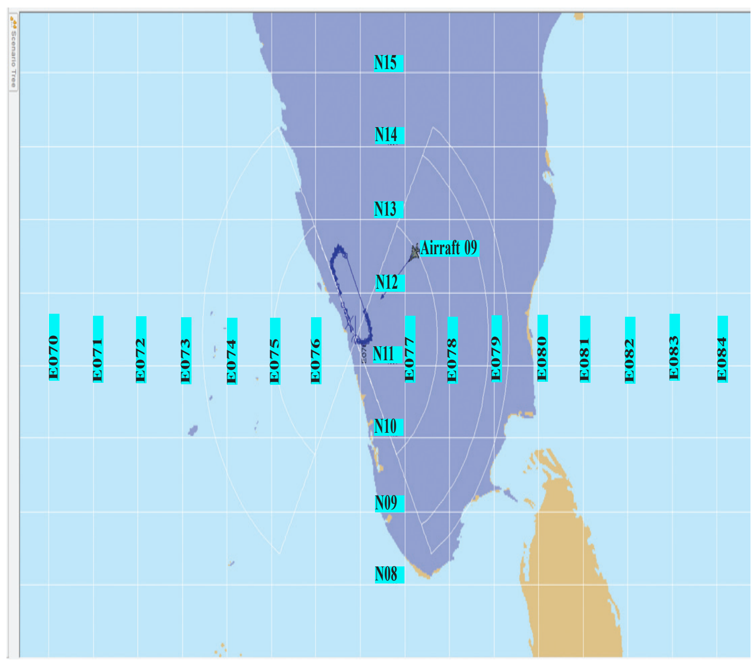
The parameters under the control of the flight test coordinator is the profiles of the test targets, the own ship and their sequencing. These optimisation criteria are chosen according to the given test card such that the flight profile chosen yields enough samples to meet the flight trial objective. Hence, optimisation consists of controlling the profiles such that maximum samples are collected during a test point evaluation.

3. FEATURES OF FPT

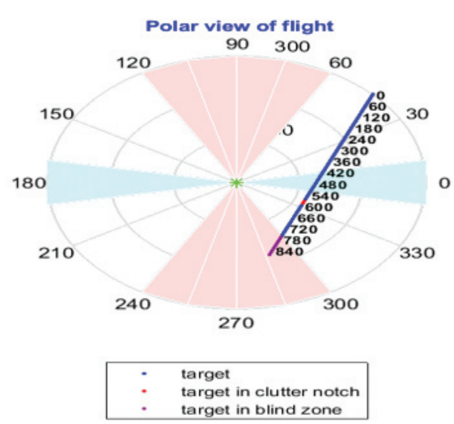
Flight planning tool is capable of predicting the expected sensor performance for a given test flight geometry. From the sequence of locations, the sensor and test target the tool computes sensor outputs like range to target versus time, range rate (Doppler) versus time, azimuth versus time, elevation versus time etc. The time step is adaptable and is typically about a second. The FPT also provides view graphs of own ship position with respect to target detection limits which are determined by the sensor design i.e. the min-max range rate, range rate clutter notch, the min-max range, the min-max azimuth, the min-max elevation. It also provides the required detection volume for each sensor.

3.1 Test Target Coverage Analysis

Flight Planning Tool is highly effective to verify sensor coverage area like range, azimuth, elevation coverage as well as other sensor requirements in terms of maximum and minimum detection ranges, Doppler etc. Figure 4(a) shows a typical scenario using Scenario Generator where sensor platform heading is at 0 degree and an inbound target at an angle of 45 degrees. Figure 4(b) shows a polar view of the flight geometry as seen from the sensor platform. The sensor platform is in the centre of the figure. The target (blue symbols) starts at around 300 km and flies inbound with around 270 m/s. The sensor platform (green symbols) starts flying with 150 m/s. The plot updates are provided every 10 second. On the other hand, Fig. 5 shows the range from the sensor platform to the target versus time. The distance to the target is about 300 km at the starting point and gets as close as about 110 km in about 550 seconds flight time. Then, the distance increases again. The target range is within instrumented range of the sensor during the entire sortie as indicated by the maximum detection range. In the Fig. 5 the shaded interval indicates when the target is at "bore sight" of the sensor platform. So during probability of detection evaluations at bore sight the samples from around 410 seconds to 510 seconds are useful and only 8 samples are collected.



(a)



(b)

Figure 4. (a) Flight profile of ownship and test target in SG, (b) Test target flight time plot with respect to Ownship.

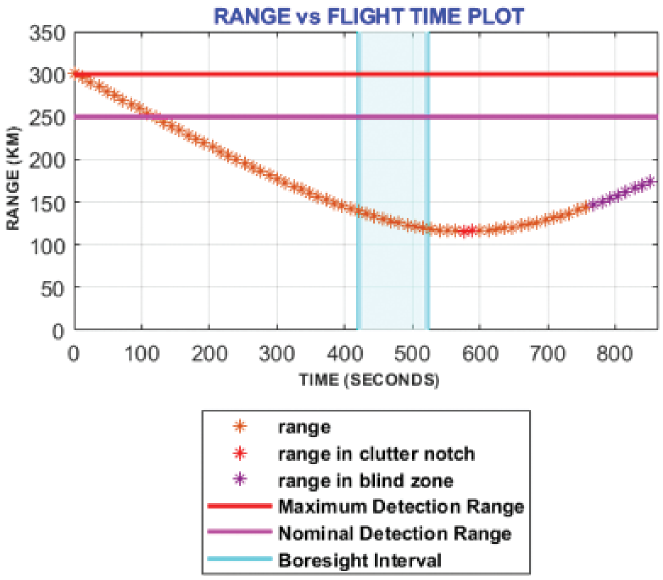


Figure 5. Test target Range – Flight Time.

3.2 Azimuth Coverage Analysis

Figure 6 shows the target azimuth angle from the sensor platform. The figure also indicates the scanning area of the sensor and the initial time at which the target is in sensor coverage cone. Only at the end (beyond about 750 seconds) the target flies out of the coverage angle. Figure also shows when the target is at bore sight (±10 degree) of the sensor. Figure 7 indicates the variation of the target elevation in degrees with respect to the ownship. From the examples view graphs, it can be noted that different graphs can be juxtaposed for better inferences. Therefore, tests for parameters which are specified at boresight (such as accuracy) can be made using this flight. However, the bore sight interval is rather short to achieve a large sample size for such tests.

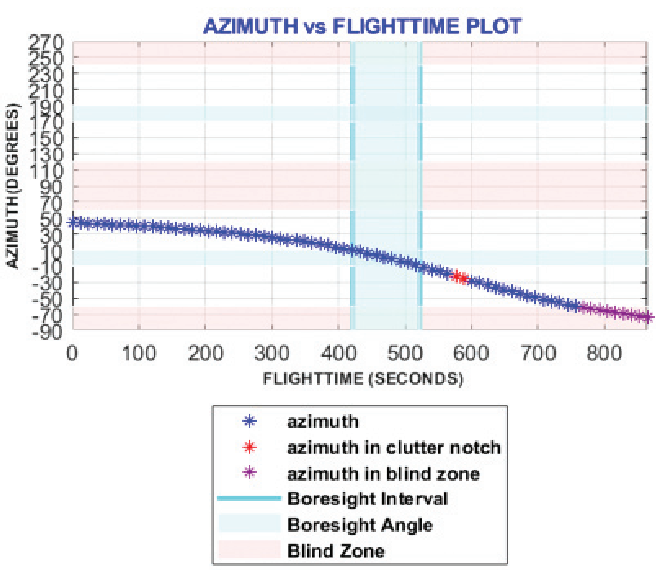


Figure 6. Test target azimuth v/s flight time.

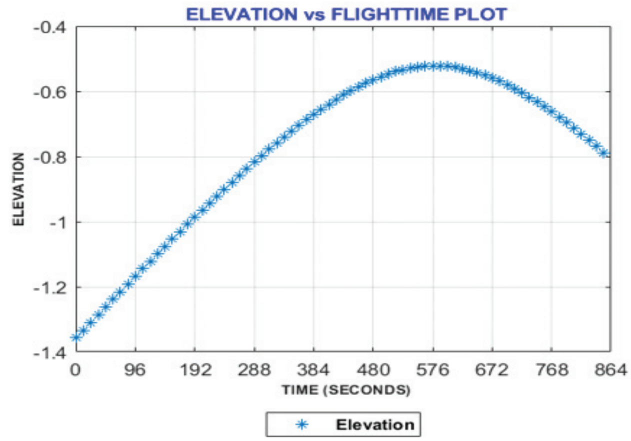


Figure 7. Test target elevation v/s flight time.

3.3 Range Rate Analysis

Figure 8 shows the range rate versus time. At the beginning, the target flies at about 45 degrees towards the sensor platform. The target speed and the sensor speed add up taking the relative approach angle of 45 degrees into account. As the target gets closer the range rate recedes below the minimum detectable range rate. In the interval where the absolute value of the target speed is below the minimum range rate the target will not be detected by the sensor and is marked in shaded region (pink). Then the range rate increases again which is high enough to be detectable.

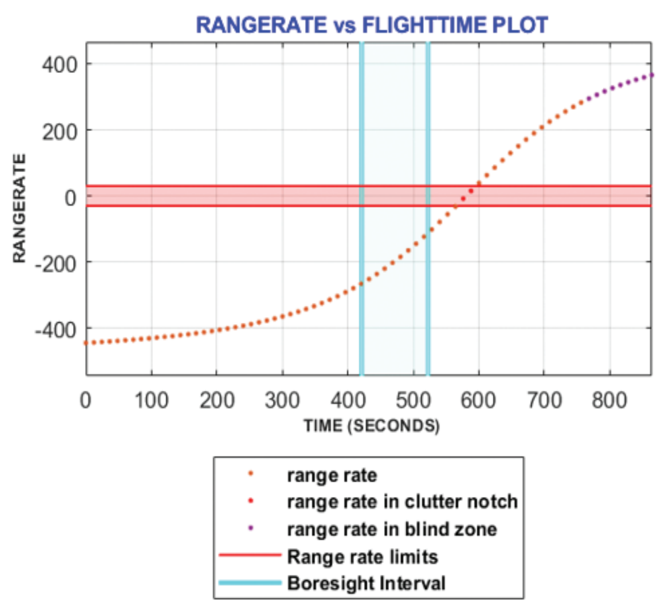


Figure 8. Test target range rate v/s flight time.

3.4 Sensor Coverage Analysis

Sensor coverage is the capability to detect objects of interest within the surveillance volume as defined in the system specification. For example, for radar coverage all detections which originate from real objects (no false alarms) are considered. Parameters which determine the detection performance are typically the RCS of target, Radar settings, Radar design parameters and performance limits such as min-max azimuth scan interval, Doppler notches. For flight trials it is not usually possible to use many test aircraft or even targets of opportunity. To increase the sample size and the measurements with in the desired range, Doppler or azimuth bin, synthetic target from the SG are used. In addition, the number of "covered az- range cells" are averaged over a height layer of the whole surveillance volume. If about 50 per cent of the cells are covered the whole volume could be declared to be covered sufficiently. In simulation this problem is addressed using a scenario where many targets are uniformly distributed across the whole coverage. Figure 9 shows sensor coverage that a target was seen at all times within a range-azimuth bin. All bins where no targets were existing was initially declared "undefined. All bins where a target was existing as determined from truth data, but not "detected" declared "not-covered".

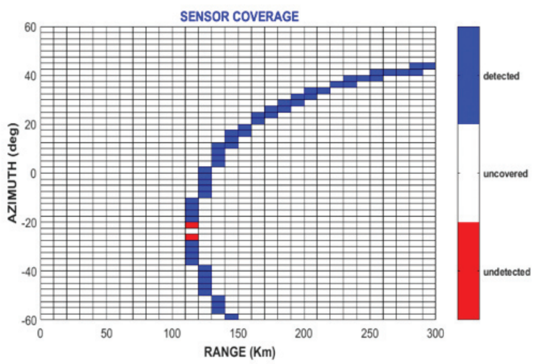


Figure 9. Sensor coverage plot for flight trial.

3.5 Probability of Detection Analysis

Flight planning Tool is capable of analysing the sensor probability of detection value where Pd is dependent on range, range rate, azimuth and on elevation with the help of the sensor model. All the modern aspects like electronic phased array, waveform diversity are factored in the sensor model. Figure 10 shows the expected probability of detection versus the time of the test flight. The Pd values are taken from a look up table model for the Radar detection probability of a standard swerling, 5 sqm target for the Air-to-Air mode. The Pd starts at about 30 per cent. When the target approaches inbound the Pd increases to almost 100 per cent at the closest target range.

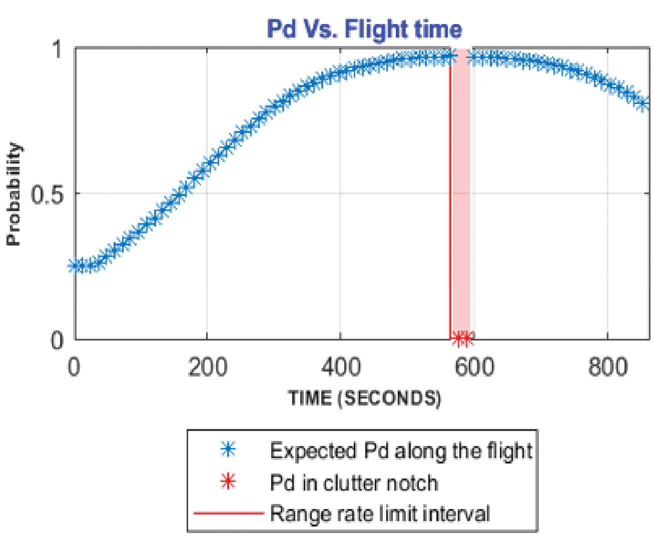


Figure 10. Pd v/s flight time.

At the closest range (at about 550 seconds into the flight) the Pd assumes zero values in the diagram (shaded region) as in this region the range rate recedes below the clutter notch. This is the part of the flight where the target azimuth exceeds the scanning angle of the Radar. The analysis shows that this kind of flight pattern could be used to verify the Radar detection range requirement.

3.6 Error Analysis

The sensor errors are an important factor affecting the quality of the sensor outputs as against the truth. The sensors errors are defined in terms of accuracy values and typically defined along range, azimuth and elevation. The sensor accuracies are a function of the Signal to Noise (SNR) ratio and follow an inverse square root relationship.

3.7 Range Error Analysis

Figure 11 computes the range accuracies of a simulated test target profile. The system specification defines certain accuracy at a defined range and the analysis shows the variation of measured accuracy from the sensor outputs. From the plot (Figure 11) we can observe that accuracy is apportioned into a fixed component and a component that varies with SNR or equivalently the range. The fixed component in this example is fixed at half the total value. Figure 11 also provides the RMS range error for the simulation.

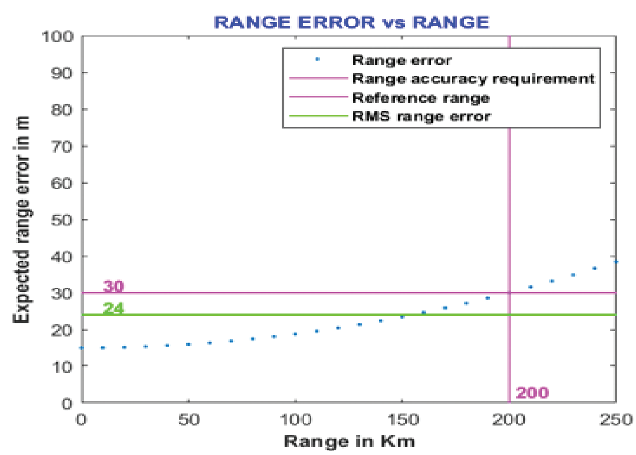


Figure 11. Test target range error vs range.

3.8 Azimuth Error Analysis

As in the range error case, the azimuth accuracy is also being apportioned into a fixed component and a component that varies with SNR or equivalently the range. The fixed component in this example is fixed at half the total value of azimuth error as the design range. Figure 12 depicts the azimuth error variations and computes the RMS value.

3.9 Overall Location Error Analysis

It is also important to compute the overall target error for various surveillance volumes. The total error is a function of both the range and the azimuth error. The azimuth error may be further a function of azimuth angle (e.g. phased array's as a result of beam broadening) Figures 13-14 provide the overall location error in rectangular and polar formats.

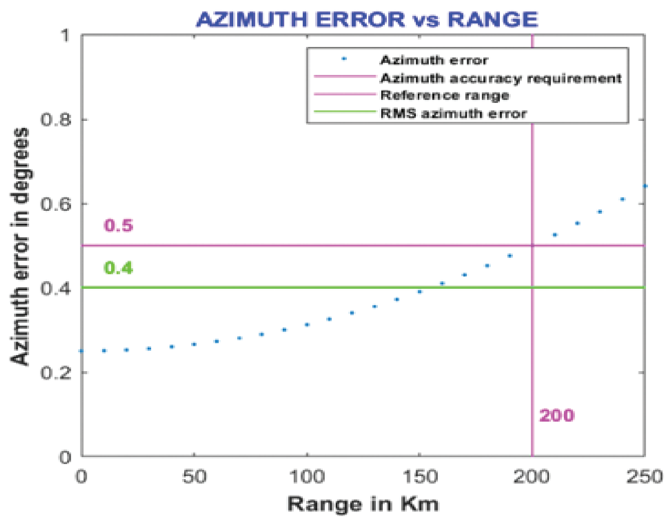


Figure 12. Test target azimuth error v/s range.

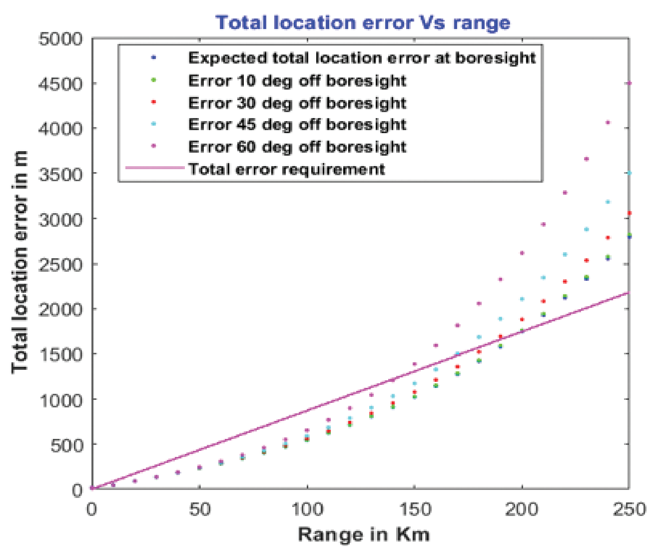


Figure 13 Total location error.

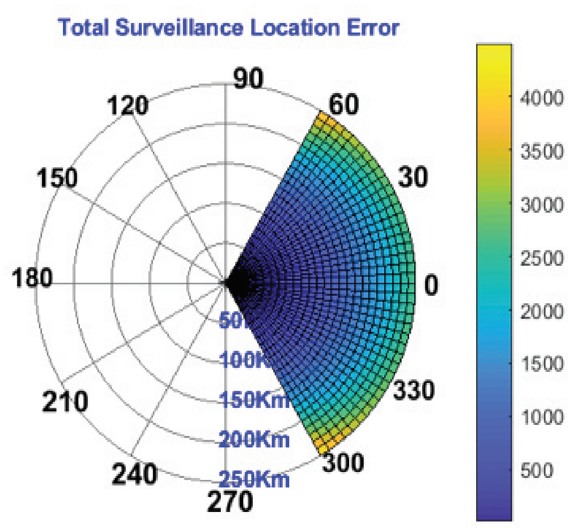


Figure 14. Total surveillance coverage error.

4. SYSTEM IMPLEMENTATION

The design of tool is generic and is based on MATLAB and VC++. Minimum requirement to run this tool in any desktop PC is Quad-core processor with more than 4GB RAM and 500 GB hard disk. The software configuration set-up is shown in Figure 15. The Scenario Generator including sensor server are integrated with display and analysis system through Ethernet interface. In the scenario generator gaming areas, ownship platforms, different type of target dynamics etc. can be defined. All the sensor simulators like PR, IFF, ESM and CSM resides in sensor server. Time server which provides time synchronisation to all subsystem are also integrated through Ethernet. The sensor models described in section 3.2 are configured in the sensor server. Based on user requirement flight profiles of ownship and targets are generated in the Scenario Generator. Ownship and target data is sent to the sensor server. The sensor server simulates the sensor detections based on sensor configuration settings. The outputs are analysed for various MOP's and MOE's and the flight test profiles iterated for optimized profiles which can compress the test time. The whole system is synchronised with NTP. The turnaround time for flight planning is typically the time required for the actual sortie or can be run 10 times faster than real time in fast forward mode. The various view graphs are generated after the scenario generation and data analysis.

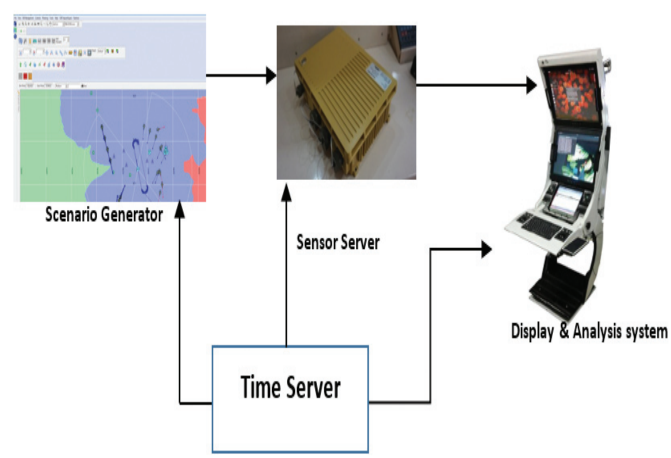


Figure 15. Integrated flight planning tool setup.

5. EFFECTIVENESS OF FPT

From the features of the FPT described in section III, and the view graphs provided, it is evident that test samples can be synthetically collected before the actual sortie is performed. Hence the tool helps to optimise the test geometries in such a way that quality samples are collected for MOP evaluation by statistical means. The flight profile generation tool can be iteratively incremented so that the best profile can be chosen for evaluation of a test point. This increases the efficiency of flight testing and reduces the flight evaluation cycle of complex airborne systems. Also it helps in organising the flight test campaigns with higher success rates where multiple airborne entities are part of the test. The tool helps to visualise, analyse and course correct the flight test geometries before the actual test. The tool also output way points that can be directly used in the mission plan. Flight planning tool can be used for planning flight trials of any airborne sensor.

6. CONCLUSION

The paper brings out the necessity of an automated software based tool for flight test planning of airborne sensor systems. The features and capabilities of such a tool is elucidated. The FPT tool provides view graphs and statistics so that the flight test geometries can be optimised for evaluation of system requirements. From the definition of the ownship platform and test target, various analysis like probability of detection, coverage and error etc. are conducted to enable collection of samples that can be used for statistical evaluation of MOP's and subsequently aggregated to the MOE's. The tool also helps in sequencing the test points. The effectiveness of the tool in compressing the flight evaluation life cycle is also highlighted.

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In this study, he has carried out the simulation work for sensor designing and detection of target, theoretical concept building and analysis of sensor detection with airborne platform.

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In this study, he has carried out the simulation work for target trajectory, analysis of sensor detection with airborne platform.

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