Research on Modeling Maritime Patrol Behavior of Aircraft on Station in Theater-Level Operation Simulation

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Abstract. In order to meet the needs of multiple types of maritime patrol aircraft for patrol missions in theater-level operation simulation, this paper builds a patrol behavior model for maritime patrol aircraft based on search type and on-station type. First of all, the search types of maritime patrol aircraft were divided into patrol, orbit, buoy and buoy/patrol based on the motion characteristics and the ability of searching submarine of different types of maritime patrol aircraft (fixed-wing patrol aircraft, patrol helicopter and patrol unmanned aerial vehicle system). Secondly, a comprehensive analysis and description of the geometry of on-station area (point, line, surface and complex) was made based on the movement characteristic of the target assets and the on-station types were divided into picket, barrier, screen, fixed region, sector and complex. Finally, the patrol behavior rules of maritime patrol aircraft on station were described based on search type and on-station type and got the patrol behavior model of the maritime patrol aircraft, which is suitable for multiple types of maritime patrol simulation.

Introduction

Theater-Level Operation Simulation

Modern military theory divides war into strategic, theater, and tactical levels. The theater level of war represents the level of command that connects the details of tactics with the goals of strategy [1]. Theater-level operation simulation is applying the modeling and simulation technology to the theater level of war and build the model of theater-level operation. Theater-level operation simulation has the following characteristics:

● Complex structure with many operational entities.

Compared with tactical level of operation simulation, there are many operational entities involved in theater-level operation simulation. For the same mission, multiple operational entities may be involved in multi-time and multi-space operations. For example, patrol missions in theater-level operations may involve different types of patrol aircraft and the way and area of patrolling will also be different.

● Low-resolution modeling and focused on the functional hierarchy.

Theater-level operation simulation does not need to implement the details of each function module under the consideration of model complexity.

According to the characteristics of theater-level operation simulation, it is imperative that a large-scale operational simulation system be able to provide an interface suitable for multiple entities and many ways to perform a task and only focused on the implementation of the functional hierarchy. This paper focuses on the maritime patrol missions in the theater-level operation simulation and analyzes the movement characteristics of different types of maritime patrol aircraft to build different models of patrol behavior.
The Related Works

The aircraft's maritime patrol refers to the alertness activity of the aircraft in the designated area. Maritime patrol plays an important role in ensuring the safety of combat forces and the victory of combat. Recently, the research on the modeling of aircraft patrol behavior at home and abroad is mainly concerned with the implementation of patrol methods and techniques [4, 5]. Document [2] established a decision support system of search submarine scheme by antisubmarine warfare patrol aircraft and put forward the decision of two level search scheme. A planning tool, called the Campaign Decision Aid, to optimize the utilization of the R-99 in its search and detection mission is developed in document [3]. In addition, the evaluation of the effectiveness of the detection behavior is also a key direction for scholars at home and abroad. Document [2] also models the evaluation of the effectiveness of the call search Anti-Submarine Warfare and the patrol search Anti-Submarine Warfare. For the study on the effectiveness of anti-submarine warfare patrol aircraft using sonobuoy system and homing depth charge, document [4] puts forward an effectiveness evaluation model based on Monte Carlo method. Currently, there are few researches on the study of aircraft patrol area at home and abroad. Document [7] focused on the research on setting of aircraft patrol area of ship escort action of ship-based helicopter in off-lying sea. In conclusion, the current research is basically the realization of the tactical level of a particular type of patrol aircraft on patrolling missions. The research on the demand of multi-type patrol aircraft in theater-level operation simulation is not yet mature. So, the research in this paper has theoretical and practical significance.

The Search Type of Maritime Patrol Aircraft

Brief Introduction of Maritime Patrol Aircraft

The *maritime patrol aircraft* is a military aircraft that performs anti-submarine, anti-ship, vigilante patrolling, mine buoy, life-saving and long-range reconnaissance missions at sea. The marine patrol aircraft is divided into fixed-wing patrol aircraft, patrol helicopter and patrol UAV system according to the structure. *Fixed-wing patrol aircraft* has the characteristics of rapid response, high search efficiency, strong attack capability, wide coverage area, strong maneuverability, etc. The representative fixed-wing patrols in the world are P-3C of the United States, Yel-38 of Russia, and "the Atlantic" ATL 2 of France. *The patrol helicopter* is mainly based on the shipboard helicopter, which has the characteristics of flexible maneuver, quick reaction speed, strong vigilance ability and good deterrent effect. Such as, the American SH-3 "Sea King" shipboard helicopter, the Russian card -27 shipboard helicopter and so on. With the development of the UAV industry, patrol unmanned aerial vehicles (UAV) system become a new mode of patrol. *The patrol UAV system* has the characteristics of strong reliability and wide patrol range, and has been widely used in military and civil fields.

Description of the Search Type

According to the motion characteristics and the ability of searching submarine of the above maritime patrol aircraft, the search type can be described as Patrol, Orbit, Buoy and Buoy/Patrol. In order to simplify the model, the aircraft that detects underwater targets only use sonobuoy system to search.

**Patrol:** The aircraft carries out dynamic search in the designated area, that is, the aircraft begins to randomly move about the region at the patrol speed.

**Orbit:** The aircraft carries out static search in the designated area, that is, the aircraft remains at a randomly selected position in the patrol area for the duration of the plan or the endurance of the aircraft. The search type is mainly suitable for patrol helicopters to search for surface target assets.

**Buoy:** This type of search is only suitable for the aircraft with the capability of deploying sonobuoys. It is similar to orbit, that is, the aircraft flies to a random position, deploys sonobuoys and remain at
that position for the duration of the plan or the endurance of the aircraft. The search type is mainly suitable for patrol helicopters to search for surface target assets.

**Buoy/Patrol:** This type of search is only suitable for the aircraft with the capability of deploying buoys. It is similar to patrol, that is, the aircraft flies to a random position, deploys sonobuoys, and randomly moves about the buoy field. The buoy field means the region in which an aircraft can receive the signal return from a sonar buoy. The radius of the buoy field is determined by the type of buoy and the patrol altitude. Generally, this radius can be no greater than the patrol radius. In order to simplify the model, the data of the radius can be input directly by the user based on the high resolution model, without considering the specific calculation method of the radius.

**The On-Station Type of Maritime Patrol Aircraft**

The conception of on-station area is given: on-station area refers to the area over the target asset where the aircraft need to carry out the mission of maritime patrol. The geometry of the on-station area is related to the type of target asset’s motion. In theater-level operation, there are many kinds of sea targets, including fixed targets (such as offshore wells, reefs), moving targets (such as surface ship and aircraft carriers) and underwater targets (such as submarine and mine). According to the motion characteristics of the target assets, the on-station area is modeled as point, line, surface and complex.

**Point On-Station Area**

When the aircraft with tasks of maritime patrol approaches the target asset, it hovers overhead the target with a specified altitude to carry out the patrol task. The aircraft remains at a point until the patrol task is completed or when the aircraft’s oil is limited. The point is called **picket**.

**Line On-Station Area**

Line on-station area is defined as the trail along which the aircraft move to detect the target maritime space. The trail is made up of a waypoint list which contains multiple waypoints and its attributes. Each waypoint has attributes of unique ID, longitude, latitude, altitude, arrive time and departure speed. For example, Table 1 shows a trail with three waypoints and its attributes.

| ID  | Latitude  | Longitude | Altitude (foot) | Arrive Time (hour) | Departure Speed (knots) |
|-----|-----------|-----------|-----------------|-------------------|------------------------|
| 1   | 25.30.51N | 056.48.41E| 2000            | 0                 | 20                     |
| 2   | 26.40.02N | 056.23.43E| 2000            | 4.083             | 20                     |
| 3   | 26.44.04N | 051.22.42E| 2000            | 19.591            | 20                     |

For fixed targets, the trail along which the aircraft move is called **barrier**. As shown in the Fig 1, aircraft will patrol along the barrier defined by a number of waypoints.

![Figure 1. Barrier on-station area](image1)

![Figure 2. Screen on-station area](image2)
For moving targets, line on-station area is described as *screen* with the reference to the moving target asset. A screen consists of a series of waypoints that are laid out relative to the reference asset. Often a screen is used to keep an aircraft moving in front of a ship moving back and forth between a set of waypoints, pausing for a specified duration at each point. The relative position of the waypoint is determined by three parameters of Range, Bearing and Pause Time.

**Range:** The distance between the aircraft on station and reference asset, where the maritime detection is to occur. The unit is nautical mile (nm).

**Bearing:** The azimuthal angle of the aircraft on station relative to the reference asset at which the maritime detection is to occur. The unit is degree (deg).

**Pause Time:** The time the aircraft is to remain at this position of the screen before proceeding to the next. The unit is minute (min).

### Surface On-Station Area

Surface on-station area is defined as a region in which the aircraft carry out the task of maritime patrol. The enclosed region is composed of a series of end to end line. There is no strict limitation on the geometry of the surface on-station area which can be either regular or irregular.

For fixed targets or targets with a small range of movement, the surface on-station area is defined as *fixed region*. Once the fixed region is defined, aircraft will carry out the task of maritime patrol within the region.

Considering moving target assets, the surface on-station area is defined as *sector*. The wedge shaped sector moves relative to a reference asset. The tasked aircraft patrols within this sector for the duration of the plan. In the Fig 3, the wedge shaped sector is uniquely determined by Min Range, Max Range, Center and Width.

**Min Range:** The minimum range the tasked aircraft can travel from the reference asset. The unit is nautical mile (nm).

**Max Range:** The maximum range the tasked aircraft can travel from the reference asset. The unit is nautical mile (nm).

**Center:** The angle at which the moving sector is centered. The unit is degree (deg).

**Width:** The angular width of the sector. The unit is degree (deg).

![Figure 3. Sector on-station area.](image1)

![Figure 4. Complex on-station area.](image2)

### Complex On-Station Area

In theater-level operation, the difficulty and complexity of the maritime patrol behavior of aircraft are increased as a result of the increasing number of target types and numbers. In order to detect the target more comprehensively and accurately, it is necessary to divide the area over the target into several parts, so as to propose the conception of the *complex* on-station area. Complex on-station area
is a combination of multiple on-station area defined above. Each area in a complex on-station area can be modeled independently and the aircraft will carry out the task of maritime patrol in turn in accordance with the schedule timetable until the last area is patrolled. For example, Fig. 4 defined a complex on-station area made up of barrier, fixed region and sector.

The Patrol Behavior Model of Maritime Patrol Aircraft

So far, we have discussed the type of on-station area and the type of aircraft’s own motion when preforming its search task. The part will get the patrol behavior model of maritime patrol aircraft on station based on station type and the search type. Table 2 shows the description of rules of maritime patrol behavior based on station type and search type.

| Station Type | Search Type | Resulting Motion |
|--------------|-------------|------------------|
| Picket       | N/A         | Upon launch, the aircraft flies directly to the picket's latitude and longitude and remains at that position. |
|              | Buoy        | Upon launch, the aircraft flies directly to the picket's latitude and longitude. The aircraft will deploy sonobuoys and remain at that position. |
|              | Patrol      | Upon launch, the aircraft flies directly to the first waypoint on the track. On arrival, the aircraft proceeds along the track. The motion continues until the aircraft reaches the endpoint of the track. |
|              | Orbit       | Upon launch, the aircraft flies directly to a randomly selected position on the barrier. On arrival, the aircraft remains at that point for the duration of the plan or the endurance of the aircraft. |
|              | Buoy        | Upon launch, the aircraft flies directly to a randomly selected position on the barrier. On arrival, the aircraft deploys sonobuoys and remains at that point for the duration of the plan or the endurance of the aircraft. |
|              | Buoy/Patrol | Upon launch, the aircraft flies directly to a random position on the track. On arrival, the aircraft deploys sonobuoys. The aircraft then proceeds along the track. The motion continues until the aircraft reaches the endpoint of the track or leaves Line of Sight of the buoy field. |
| Barrier       | Patrol      | Upon launch, the aircraft flies directly to the first screen station. The aircraft then moves within the designated patrol radius of this fixed waypoint for the specified Pause Time. It then flies to the next screen station and again moves about. This continues until it reaches the last screen station. |
|              | Orbit       | Upon launch, the aircraft flies directly to the first screen station and remains there for the specified Pause Time. It then flies to the next screen station and remains there. This continues until it reaches the last screen station. |
|              | Buoy        | Upon launch, the aircraft flies directly to the first screen station, deploys sonobuoys and then remains at this location for the specified Pause Time. It then flies to the next screen station, drops buoys, and remains there for the Pause Time. This continues until it reaches the last screen station. |
|              | Buoy/Patrol | Upon launch, the aircraft flies directly to the first screen station and then deploys sonobuoys. Next, the aircraft moves about the buoy field. Patrolling occurs for the specified Pause Time. The aircraft then flies to the next screen station, deploys sonobuoys and again moves about. This continues until it reaches the last screen station. |
| Screen       | Patrol      | Upon launch, the aircraft flies to a randomly selected position in the patrol area. The aircraft begins to randomly move about the region. |
|              | Orbit       | Upon launch, the aircraft flies directly to a randomly selected position in the patrol area. On arrival, the aircraft remains at that position for the duration of the plan or the endurance of the aircraft. |
|              | Buoy        | Upon launch, the aircraft flies directly to a randomly selected position in the patrol area. On arrival, the aircraft deploys sonobuoys and remains at that position for the duration of the plan or the endurance of the aircraft. |
|              | Buoy/Patrol | Upon launch, the aircraft flies directly to a randomly selected position in the patrol area. The aircraft then deploys sonobuoys and begins to randomly move about the buoy field. |
| Sector      | On-Station Type                                                                 |
|------------|--------------------------------------------------------------------------------|
| Patrol     | Upon launch, the aircraft flies to the user-defined sector. The aircraft then moves randomly about, all the while remaining in the moving sector. |
| Orbit      | Upon launch, the aircraft flies to a randomly chosen point in the moving sector. It then stays at that relative location to the moving reference asset for the duration of the plan. |
| Buoys      | Upon launch, the aircraft flies to a randomly chosen point in the moving sector. The aircraft then deploys sonobuoys. Next, the aircraft stays at that absolute location above the buoy field until the buoy field monitor time expires. At this time, the aircraft moves to “catch up” with the moving sector. The aircraft flies to a new random location in the moving sector and repeats the process. |
| Buoy/Patrol| Upon launch, the aircraft flies to a randomly determined position in the moving sector and deploys sonobuoys. Next, the aircraft moves randomly about staying within a radius of the buoy field. When the buoy field monitor time expires, the aircraft moves to the sector’s new position and repeats the process. |

| Complex     | Varied/Multiple                                                               |
|------------|--------------------------------------------------------------------------------|
| On-Station Type | The Complex station type allows for the creation of a sortie that sequentially patrols multiple regions. The search type can be individually set for each region. When finished the patrol task, the aircraft will then transit to the next region. When all regions have been patrolled, the aircraft will return to base. |

### Search Type

![Figure 5. The patrol behavior model of maritime patrol aircraft on station.](image)

**Summary**

In the theater-level operation, there are many operational entities involved. For the mission of maritime patrol, there are many types of maritime patrol aircraft. So, when modeling and simulating theater-level operation, it is necessary to provide interfaces that enable multiple types of maritime patrol aircraft to perform patrol missions. Based on the motion characteristics and the ability of searching submarine of maritime patrol aircraft, this paper classifies the search types of maritime patrol aircraft as patrol, orbit, buoy and buoy/patrol. Put forward the conception of on-station type and
classify the on-station types as picket, barrier, screen, fixed region, sector and complex based on the geometric characteristics of on-station area (point, line, surface and complex). Each type of on-station is modeled and the geometry of each on-station area is determined through parametric modeling. Finally, the rules of maritime patrol behavior are described by combining the search type of maritime patrol aircraft and the on-station type to get the maritime patrol behavior model that can be applied to many types of maritime patrol aircraft. The results of this paper can provide multiple types of interface for the realization of maritime patrol missions in large-scale simulation systems.

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