Modeling and Simulation Design for Load Testing a Large Space High Accuracy Catalog

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ABSTRACT

A large High Accuracy Catalog (HAC) of space objects is essential to enabling Space Situational Awareness (SSA). The Joint Space Operations Center (JSpOC) Mission System (JMS) has a requirement for a HAC that would serve as its referential foundation. The capacity of the HAC needs to support a large number of space objects (100,000+) in order to allow the effective analysis of potential space events and to allow command and control of space forces. Testing the capacity of the HAC is vital, but is complicated by the fact that the large HAC has not yet been built and the current space sensor network does not support the generation of observations for the objects that would be added to the large HAC.

We must examine the factors that affect the design of a model version of a large HAC, and the simulation of space object observations that would drive the computational load on the catalog maintenance functions of the HAC software. Synthetic objects added to the catalog must be representative of the real-world space objects that will eventually be added to the HAC when space sensor capabilities are improved. We also need to examine the various methods for generating simulated space sensor observations, and the advantages and disadvantages of each approach. The easiest approach to simulating observations is to generate them using look angle algorithms. However, this approach may have limitations due to the dependent nature of the predicted observations. Other methods examined are replication using spatial or temporal displacement of real-world observations for representative objects.

Finally, we must examine uncorrelated tracks (UCTs) and how to simulate them for HAC load testing. We would expect to see a larger number of UCTs when the space sensor network is improved. We must decide how UCTs will be handled during the load test. The number and timing of UCTs needs to be carefully selected to appropriately model this load component for the HAC maintenance function.

In all of our Modeling and Simulation selections, we must try to make design decisions that will produce the most realistic HAC for testing. Load testing will give us the confidence that the hardware and software created for HAC development and maintenance will support the task as we add objects to the catalog over the coming years.

1. INTRODUCTION

A large High Accuracy Catalog (HAC) of space objects is one of the primary objectives of the Joint Space Operations Center (JSpOC) Mission System (JMS) program. The HAC will enable more effective command and control of space forces throughout the entire range of military operations. It would also have benefits for safety and efficiency of commercial space operations. Although the required size of the HAC has varied recently due to cost and schedule trade-off considerations, it is clear that the JMS HAC needs to be much larger than the current HAC.

The existing HAC contains approximately 20,000 objects and consists of operational satellites, inactive satellites, and orbital space debris larger than 10 centimeters in size [1]. Fig. 1 shows a representation of the existing tracked space objects based on an unclassified catalog. The HAC is maintained by the JSpOC using the Space Defense Operations Center (SPADOC) and CAVENET systems using observations from the Space Surveillance Network (SSN) and Air Force Space Surveillance System (AFSSS) [2]. SPADOC has reached the end of its useful life, and presents limitations both in maintaining the existing catalog and in expanding the catalog to include additional space objects [3]. The existing HAC is limited in the number of Orbit Determination (OD) updates it can process and in the number of Uncorrelated Tracks (UCTs) it can transform into trackable objects. It is also limited in its ability to identify potential orbital conjunctions, using a separate screening process rather than an automated identification process after an updated OD or addition of a new object [4].

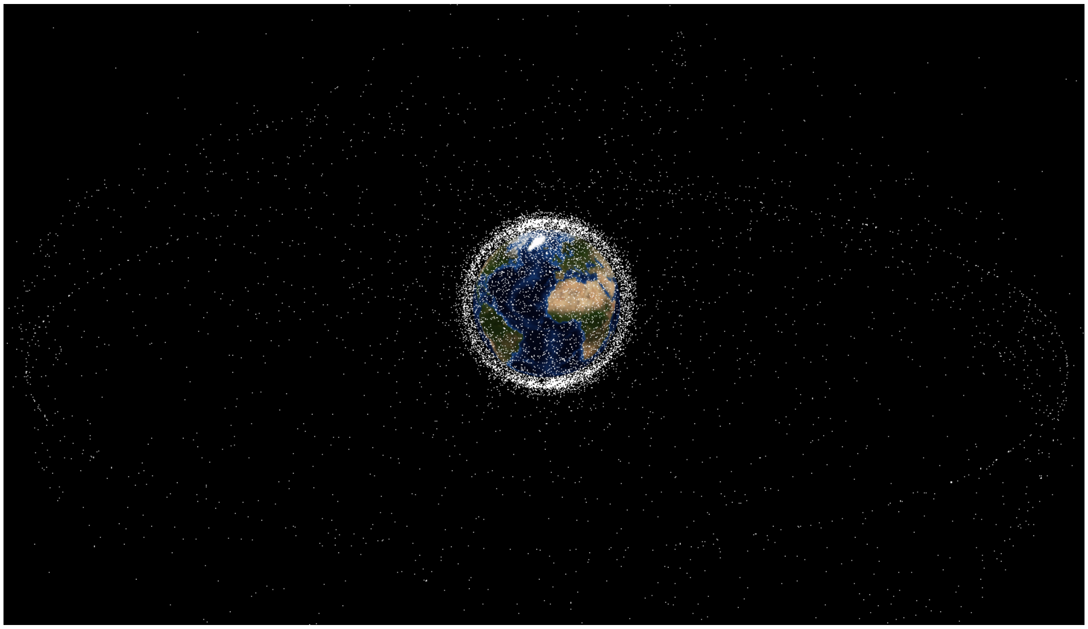

Fig. 1: A Representation of today's Space Object Catalog

As new sensors such as the Space Base Space Sensor (SBSS) and Space Fence come on-line, even more space objects between 5 and 10 centimeters in size will be added to the HAC [5]. Hundreds of thousands of additional observations from these objects will be fed into the HAC and will present an additional processing load. As a result, the new HAC will need to accommodate more than 100,000 space objects. It is critically important that the JMS HAC be load tested to ensure its architecture is adequate to handle the additional load and is expandable to process even more space objects as needs arise [6].

2. HAC LOAD TESTING CONSIDERATIONS

The JMS HAC will need to be able to handle the load of receiving observations, updating ODs for known objects, correlating UCTs into trackable objects, and conducting orbital conjunction analyses for changes to the space catalog. I will refer to these processing loads as the catalog maintenance load. The HAC will also have additional loads caused by space launch and other ad hoc conjunction analyses, change detection, catalog access to enable other analytical functions, and other database update tasks. I will refer to these processing loads as access loads.

A realistic and operationally representative load test on the JMS HAC will require simulating both the maintenance loads and access loads on the system. Access loads on the catalog are easily simulated using a variety of load testing tools because access loads are initiated through an information service interface. Once realistic access activity levels are identified, the information service calls can be generated and fed to the system by the load software. Operationally realistic service calls can be generated by chaining information service calls together where the results from one service call are used to populate the parameters on subsequent service calls. The generation of access loads is beyond the scope of this paper, but is an important part of the overall load testing planning for the HAC.

Testing maintenance loads on the HAC is more problematic--it's a kind of Catch-22. In order to precisely load test the HAC, we need it fully populated, but that cannot be done until it is operational and receiving the additional observations from the new space sensors. Obviously, testing with the current catalog would be of no use in evaluating the acceptability of the HAC for developmental and operational test purposes. So, in order to do developmental load testing that can provide effective feedback to the developers and program office, we need to create an operationally realistic large catalog to be used in Modeling and Simulation of the maintenance load.

The load testing model for maintenance loads on the HAC needs to include additional synthetic space objects and software to generate and inject simulated observations at a much higher level than is currently available. The observation generation software must generate observations correlated to the synthetic space objects and UCTs not correlated with any of the catalogued objects. Once the maintenance load model is finalized, the synthetic space objects would be added to the existing catalog, and the simulated observations would be fed into the HAC along with the real-world observations. Conjunction assessment will be spawned automatically by the HAC any time an OD is completed. As a result, this simulation would generate the appropriate maintenance loads on the HAC that along with the simulated access loads would allow evaluation of the system loading and capacity.

3. CREATING A LARGE CATALOG FOR LOAD TESTING

A primary assumption of creating the large test catalog is that it will represent the final size of the HAC and will not cover the transitional state from the current HAC size to its ultimate capacity. This assumption is required because the transition is expected to take too long to be included in the test period. We should further assume that as the HAC is expanded in size, UCTs will be "throttled" and processed in a priority order. This assumption is necessary due to limitations in sensor tasking. If these assumptions are valid, the highest load on the system would be after it is fully populated and receiving the full complement of observations.

The large test catalog would consist of the full complement of existing, tracked space objects and a number of synthetic space objects that would make up the balance of the HAC capacity. It is extremely important that the synthetic objects accurately characterize existing orbital debris in terms of orbital height and inclination. It is also important that these synthetic objects not create artificial high density "clumps." These factors are important to prevent an artificially high number of orbital conjunctions and the concomitant conjunction analysis processing that it would drive. The majority of the synthetic objects would be in Low Earth Orbit (LEO), but other orbital regimes must be represented as well. Ideally, we would use an estimated profile of orbital debris objects and would create synthetic objects in proportion to their representation in the profile.

The synthetic objects can be modeled from existing catalogued debris objects with similar orbital characteristics. Although we cannot exactly model the additional debris objects until they are added to the HAC, using existing debris objects may be as close as we realistically can get. Fig 2 shows a representation of how the large HAC might look if plotted around the earth.

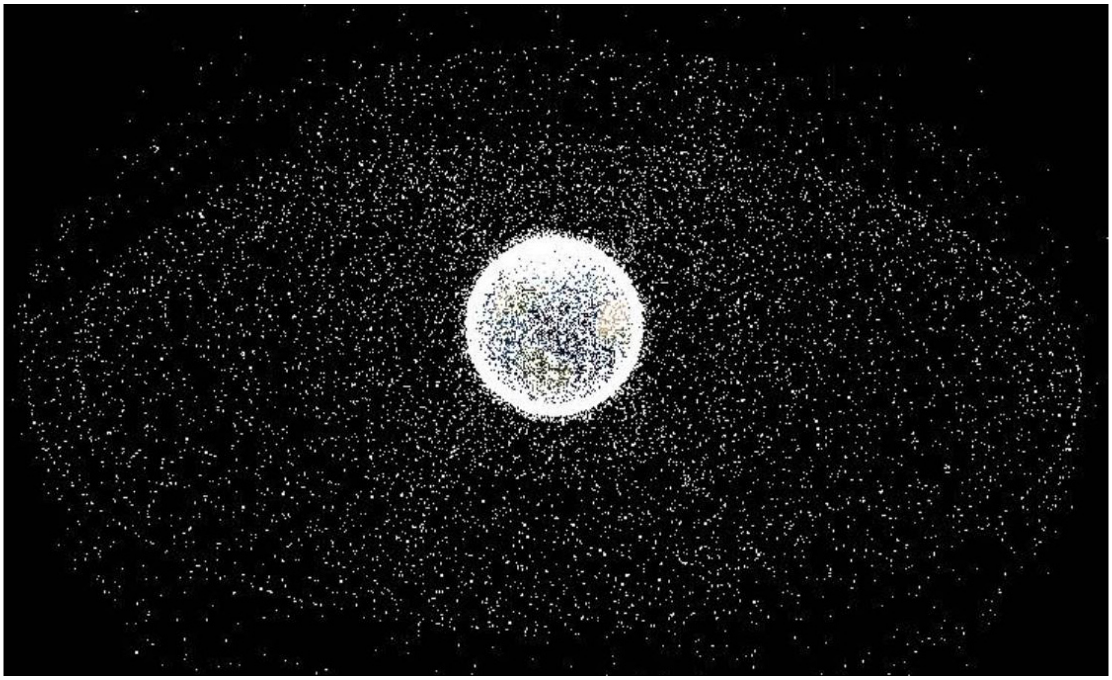

Fig. 2: A representation of how a large space object catalog might look

4. GENERATING OBSERVATIONS FOR LOAD TESTING

Once the large HAC is populated, observations must be generated to drive the primary catalog maintenance load. The simulated observations will be injected along with the real world observations to create the composite load. The simulated observations will be correlated with a synthetic space object in the large test HAC. UCTs are discussed in the next section. The primary question for the correlated observations is how best to generate operationally realistic data. I am aware of two methods of creating these observations: using look angle algorithms, and spatial or temporal displacement of real-world observations.

Generating observations from look angle algorithms is relatively straightforward. Once the object is added to the catalog, its Special Perturbations (SP) orbital information is fed to the look angles algorithm and it is propagated using SP theory. The algorithm then generates observations for the selected ground sites. Air Force Space Command's (AFSPC's) Astrodynamic Standard Look Angle Module (LAMOD) is capable of producing observations in this way [7].

A potential problem with this method is that initially the generated observations may be too good--"it's right where we expected it to be." Observations that are too good could cause the OD process to complete more quickly than it might otherwise, resulting in an artificially low load. One method of compensation for this potential issue is to modify the observations with sensor noise. If AFSPC has adequate data on sensor noise, these data could be used to determine the appropriate amount to inject in generated observations. Otherwise, the white noise method described in [8] could be used to inject noise. The process is depicted in Fig 3.

The advantages of this approach are simplicity and controllability. Not only is implementation easy, but you can generate as many observations as you need to meet load targets. The disadvantage of this approach is that it is somewhat open-loop. Several load tuning factors (sensor noise, number of observations) are set without direct feedback from real world data.

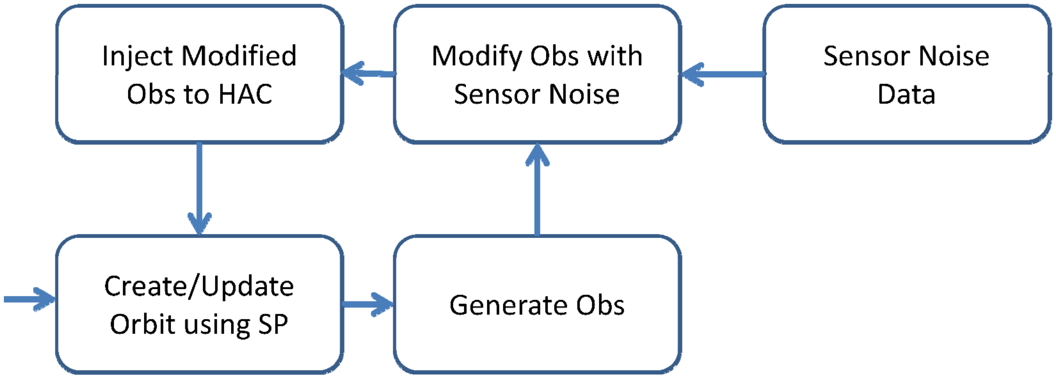

Fig. 3: Flow diagram for look angle generated observations

A second potential approach is to replicate real-world observations by spatially or temporally displacing them. These displaced observations would be associated with synthetic space objects that were created by spatially or temporally displacing them from the original object. Spatial displacement could be implemented by creating fictional sensors identical to a real-world sensor, but in a different location. The observations could then be adjusted to account for the flattened earth geoid. Temporal displacement would simply shift the timing of the observations. For either of these displacement strategies, the synthetic objects would need to be created from the generated observations. This would require an extensive preparation time period. Spatial and Temporal observation displacement are depicted in Fig 4. The process of using displaced observations is depicted in Fig 5.

The advantage of this approach is realism. Both the synthetic objects and the observations are based on real-world data. The number of observations would be consistent with operational experience with similar objects and sensor noise is built into all observations. The disadvantage of this approach is that it is somewhat more difficult to control the number of observations injected into the HAC. The number of observations would be a multiple of the actual observations on the replicated objects. If these observations did not get us to our requirement for observation processing, it would be more difficult to increase them. However, it would be possible to supplement the number of observations by generating additional ones using the look angle algorithm strategy.

Either of the previously discussed approaches will create large numbers of observations that will generate a catalog maintenance load. They would drive observation processing, OD updates, and automated orbital conjunction assessment. The one additional load we need to generate is UCT processing.

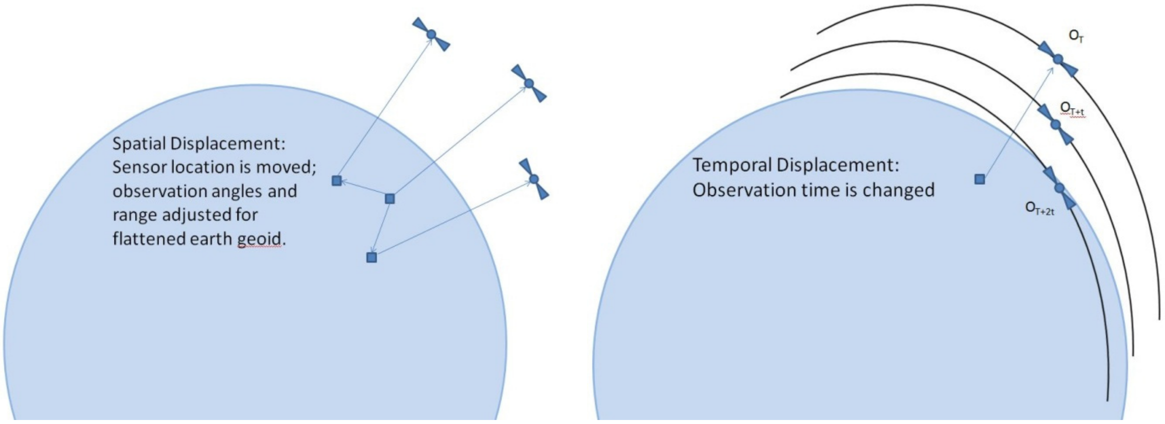

Fig. 4: Spatial and temporal displacement of observations illustrated

5. UNCORRELATED TRACKS

Uncorrelated tracks create an additional and important load on the HAC catalog maintenance function. As stated above, we assume during the catalog building phase that UCTs will be "throttled"; i.e. only as many UCTs as can be efficiently processed will be accepted. We also assume they would be correlated and added to the catalog in a priority order as sensor tasking and quality observations permit. Since we will be load testing with a nearly fully populated catalog, two questions remain: how many UCTs should we realistically expect; and how should we generate them.

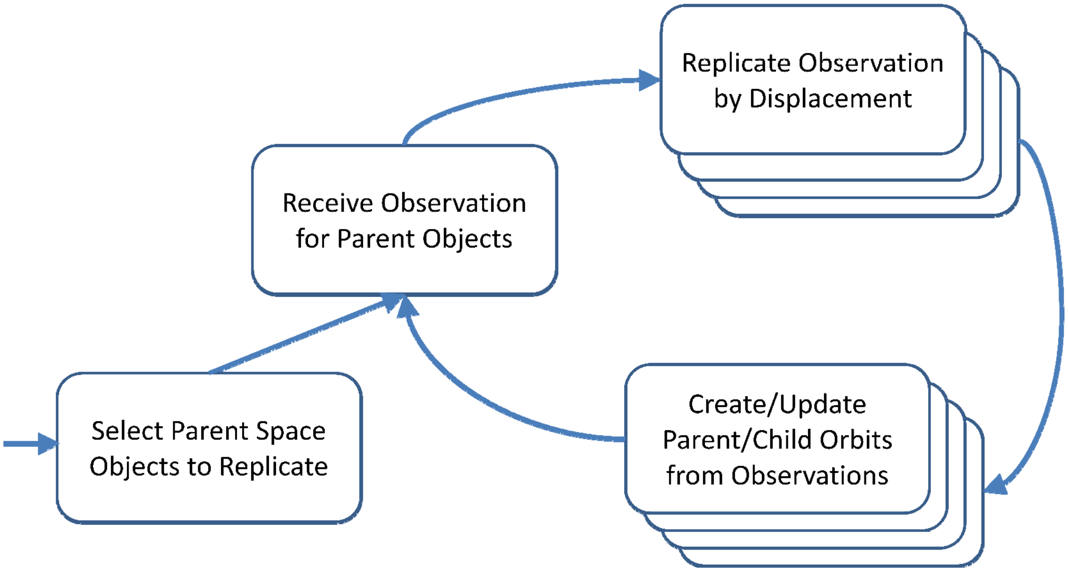

Fig. 5: Flow diagram for observations generated by displacement

Lacking further data on the subject, the simplest approach is to linearly scale up the number of UCTs with the overall size of the HAC. Although the number of UCTs will initially be very high when new sensors with enhanced capabilities become available, the rate of UCTs should diminish somewhat when the HAC is close to being fully populated. Since HAC sizing requirements are based on the estimated number of space objects larger than a particular size, we could assume that during steady-state operations, the rate of UCTs would be directly proportional to the size of the catalog. Additional study may give us a better estimate of the number of UCTs, but linear scaling is a departure point for further discussion.

Generating UCTs should be a relatively simple process since no associated space objects need to be created. We could replicate existing UCTs by spatial or temporal displacement, and they would adequately serve to create the UCT component of the HAC catalog maintenance load. For the purpose of the load testing, it is not necessary to resolve the UCTs. Simply processing the UCTs and generating the recommended sensor tasking is the important element of the UCT HAC maintenance load.

6. CONCLUSION AND AREAS REQUIRING ADDITIONAL WORK

This paper has presented several candidate methods of creating a large catalog for load testing the JMS HAC. It identifies catalog maintenance load components and methods for generating them. However, this is just the first step in a relatively lengthy process that will result in the selection of specific methods, development of model components, and software to implement the simulation. The modeling and simulation methods need to be reviewed by the JMS Program Office, AFSPC, USSTRATCOM, Air Force Operational Test and Evaluation Center, and the Director of Operational Test and Evaluation staff. Finally, the model and simulation software will need to be subject to a Verification and Validation process.

Additional research is needed in several areas. A model catalog profile needs to be developed that distributes the synthetic space objects into groupings based on orbital height and inclination. Sensor noise data needs to be codified into a form that can be used to modify calculated observations. Trade-off studies need to be performed to determine the best method for generating observations for injection into the HAC. Additional study is needed to estimate the appropriate number of UCTs to be injected during fully populated, steady state operations. Finally, all simplifying assumptions need to be validated.

The JMS HAC will be an important National asset for the future command and control of US space forces. Increased capacity is one of the HACs most important features. Early load testing of the HAC is critical for ensuring a robust and expandable architecture that can provide Space Situational Awareness to our space leaders.

7. REFERENCES

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