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Modeling an Autonomous Underwater Vehicle (AUV) with Matlab and Simulink

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Abstract

This article presents a modeling of the dynamics of the DEF-ALFA autonomous underwater vehicle designed within the search project PID UNDEFI 484/2019 of the National Defense University. This paper proposes an alternative method for classical method for the study of the dynamic characteristics of AUVs to apply it in the DEF-ALFA. Based on a methodology that uses the similarities between AUVs and airplanes, a simulation was obtained that allows analyzing the behavior of the AUV without the need to perform complex calculations.

I Introduction

1. Background

The advantage of simulation using components of some computational programs is that the analytical solution of many of the equations of a real model is extremely complex. For this reason, simplifications on the geometry of the UAV are usually used to simplify the calculations, or operating conditions such as low speed, movement limitation, etc. are imposed. In this case, the autonomous underwater vehicle is the following:

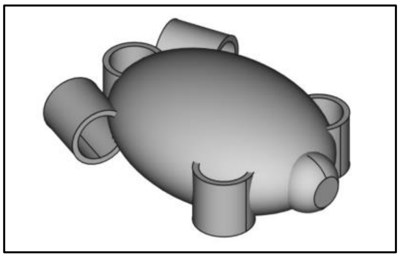

Figure 1

This vehicle was designed as a light AUV to carry out inspection of hulls, submerged structures, sampling of marine fauna and oceanographic tasks in general. It follows from the type of operation that is intended for it, that its displacement will not be at high speed, nor will it require sudden maneuvers, which would allow making some assumptions to simplify the analytical solution of its dynamic equations. Thus, the simulation through the use of Matlab and Simulink, allow to see the characteristics of its operation from a simpler modeling than the application of the UAV equations.
The simulation used can be seen in the following figure:

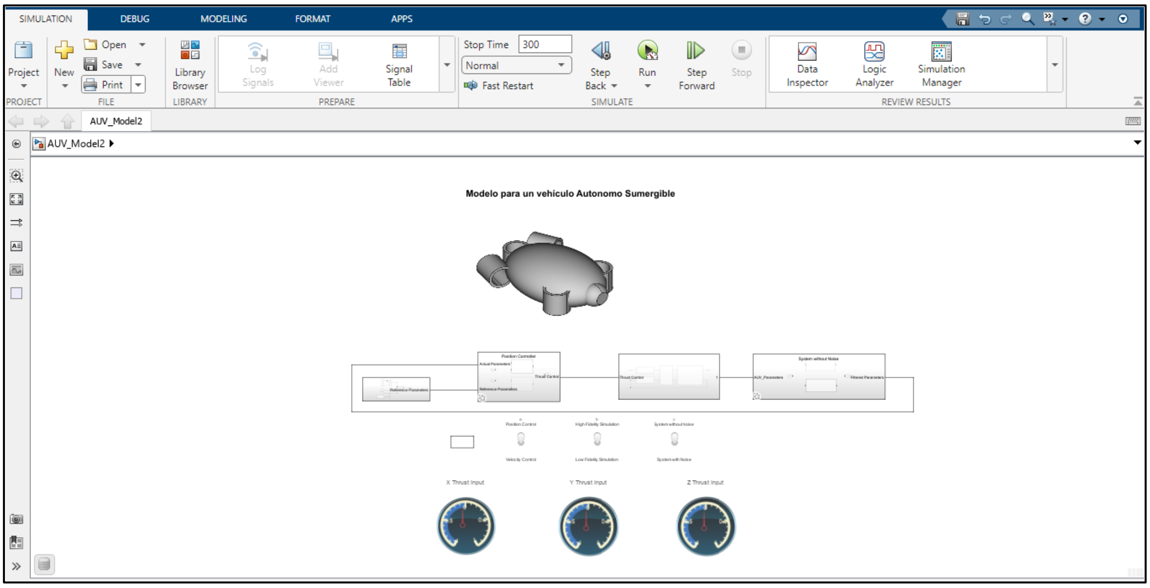

Figure 2

II. Materials and Methods.

2.- Considerations about the model that was used

Following the methodology proposed by Veeralla [b], the first consideration is about the dynamics of the submarine, which has many similarities with airplanes, considering that the main forces and moments that act generate a system with 6 degrees of freedom, the which we can see in figures 3 and 4.

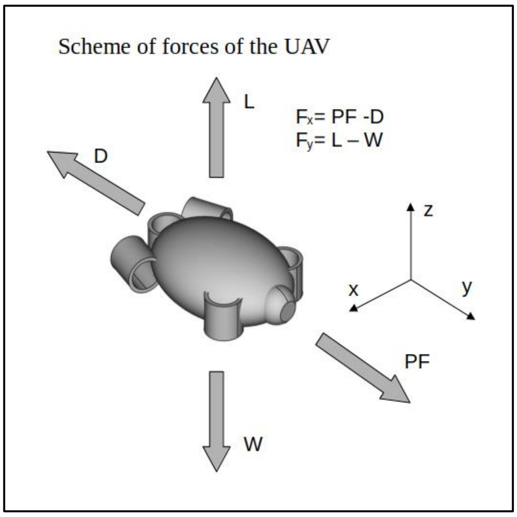

Figure 3

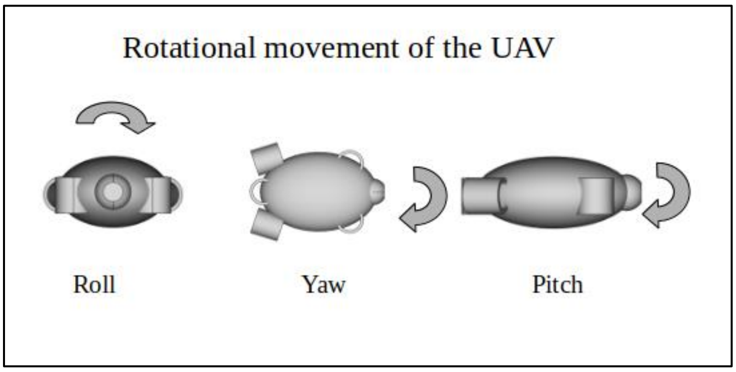

Figure 4

Since an analogy can be made between the UAV and an airplane, using Simulink's AEROSPACE BLOCK SET there are tools that allow solving the equations of motion without performing complex calculations, one of which is the 6-DOF BLOCK (Figure 5), which allows the integration of forces and moments in all directions.

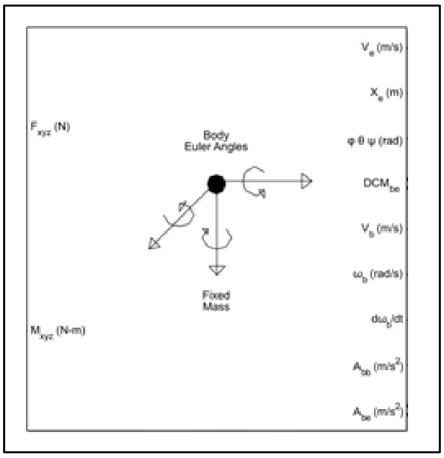

Figure 5

Other tools to use are the ROTATION BLOCKS and the COORDINATE TRANSFORMATION BLOCKS (figure 6), which allow the alignment of the forces and moments in the appropriate directions.

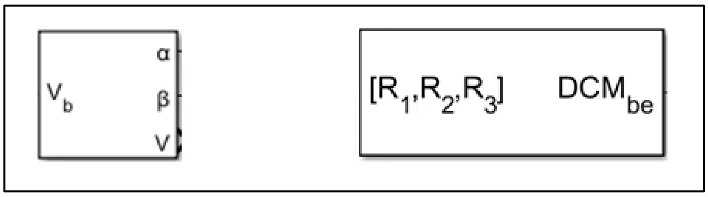

Figure 6

Finally, the IMU SENSOR MODEL is used to introduce disturbances in the variables used as they would occur in reality.

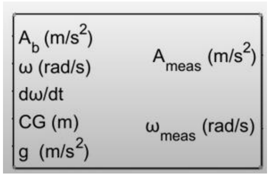

Figure 7

In order to simulate the behavior of the AUV in a real way, we include it in a functional environment, for which control elements that act on the UAV must be introduced, generating for this case the diagram shown in figure 8.

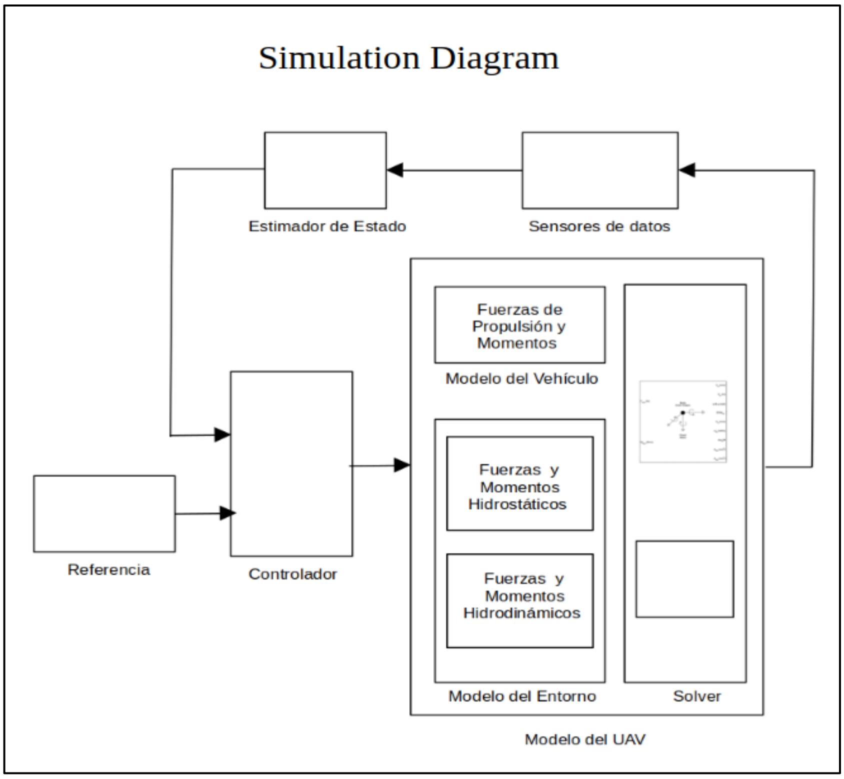

Figure 8

The reference block generates an input that represents a certain desired position or speed, the controller acts based on this and the estimate made by the sensor and the estimator on the location or state of the UAV model. The UAV model, for its part, is composed of a model of the propulsion forces and moments and of an environment model that includes hydrodynamic forces and moments and hydrostatic forces and moments as components.
The model is operated by estimating the acting forces, for which, if you introduce the action of the propulsion motors and the reactions of the environment on the vehicle, with the UAV model already built, the open-loop behavior is tested and it is verified that type of control to apply so that this is optimal according to the desired operating conditions. The methodology used in the open-loop study process was based on the work of Ridley, Fontan and Corke [a]. This process is described in the following figure:

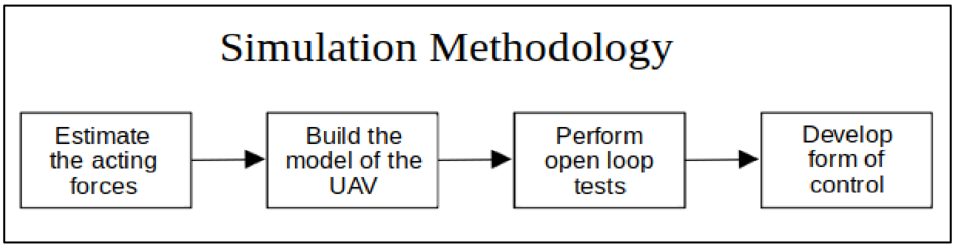

Figure 9

3.- Implementation of the Model

The components of the System of the implementation carried out in Simulink (figure 10) are those that were defined in the structure of the functional model described above and whose subsystems are the following:

- *Subsystem 1 - Propulsion Forces and Moments:*
- *Subsystem 2 - Environmental Forces and Moments*
- *Subsystem 3 - Combine Forces and Moments*
- *Subsystem 4 - Dynamic Solver*

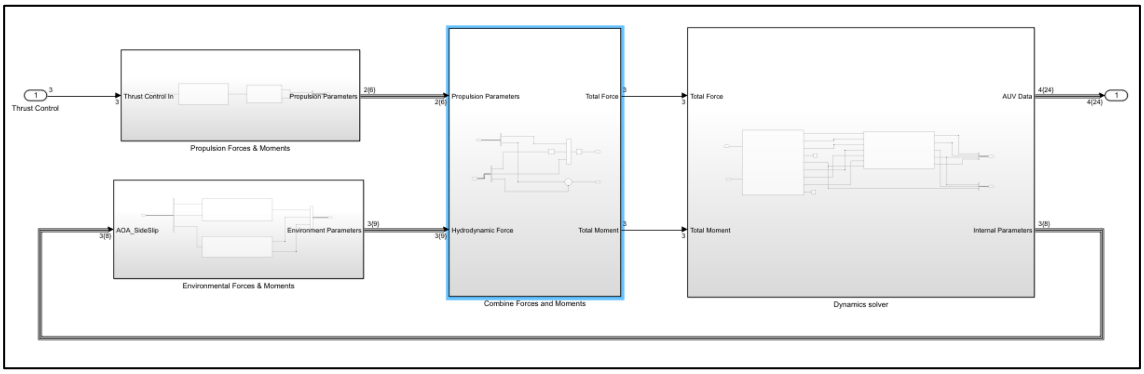

Figure 10

The Propulsion Forces and Moments Subsystem is composed of an Inputs Command to Thrust subsystem that receives the inputs from a controller that transforms them into signals to the motors so that they generate the actions on the UAV that in the Force and moments due to Thrust block. where the drive signals are transformed into propulsion forces and moments constituting the propulsion parameters: Propulsion parameters. This can be seen in figure 11.

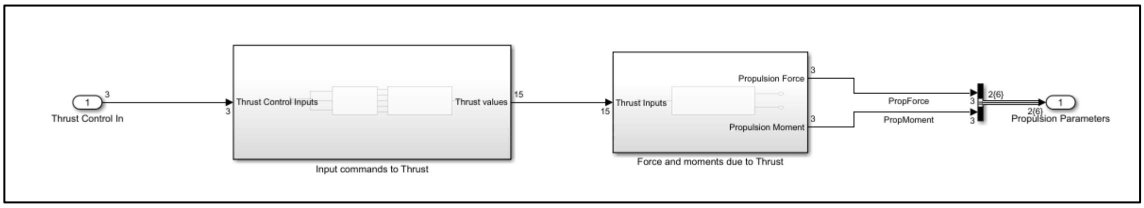

Figure 11

The transformation of the inputs into thrust drive of the motors is done by transforming these inputs into PWM signals for the motors, for which a transfer function obtained from the SYSTEM IDENTIFICATION TOOLBOX is used, which uses Blue Robotics data obtained from T100 motors and T200, similar to those used by the UAV. This block is shown in the following figure

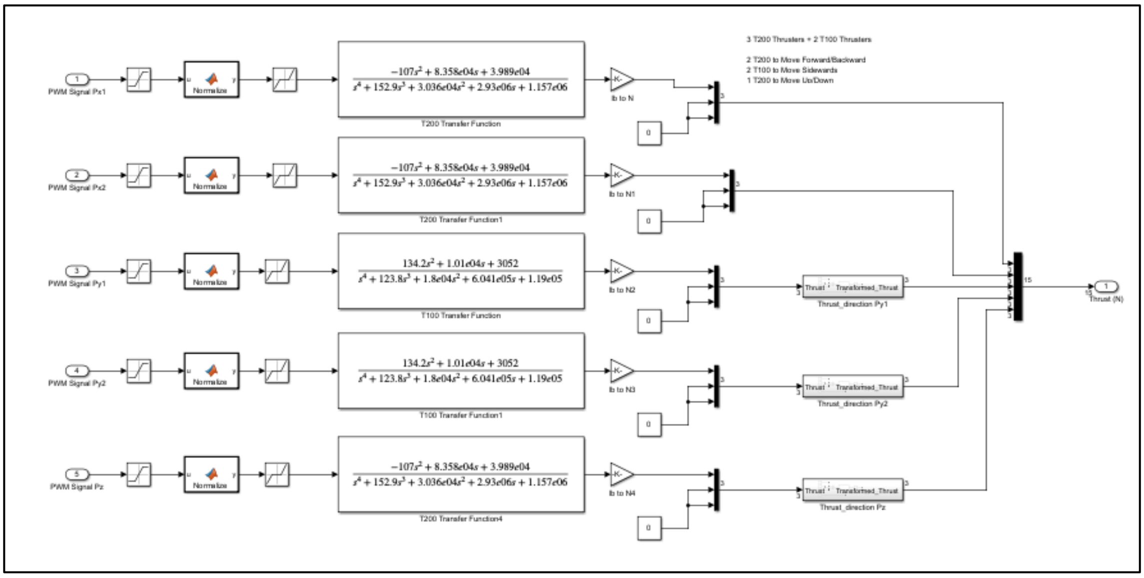

Figure 12

The Environmental Forces and Moments Subsystem is made up of a subsystem that obtains the hydrostatic forces and another that obtains the hydrodynamic forces or moments, as seen in figure 11.

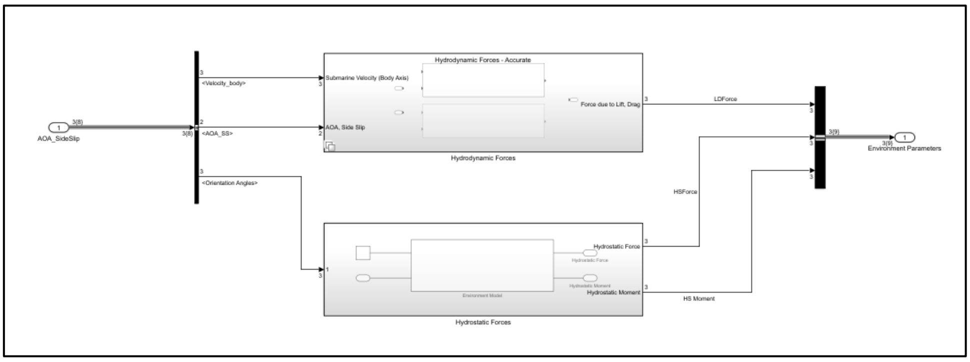

Figure 13

The hydrostatic subsystem: Hidrostatic forces, basically uses the weight and pressure of the water on the UVA, as can be seen in the parameterization shown in figure 12.

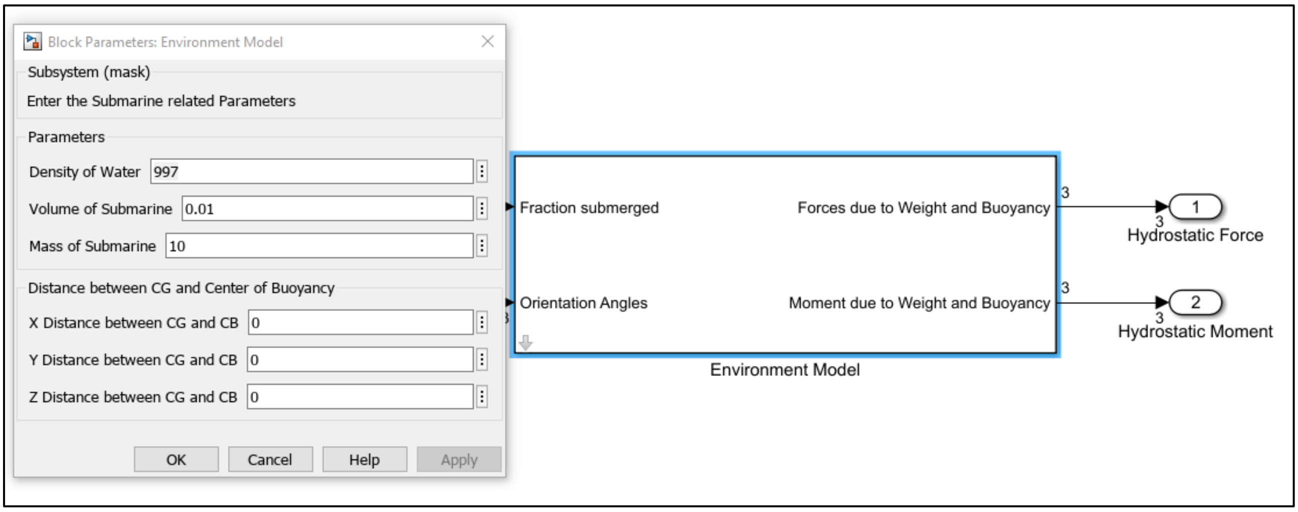

Figure 14

The subsystem that contemplates the hydrodynamic forces: Hydrodynamic Forces can be worked in precise or imprecise mode, for this the model can be simplified by introducing restrictions that reduce the complexity of the calculations in exchange for the loss of precision, since the choice is possible the model was simulated using the Hydrodynamic Forces-Accurate block.

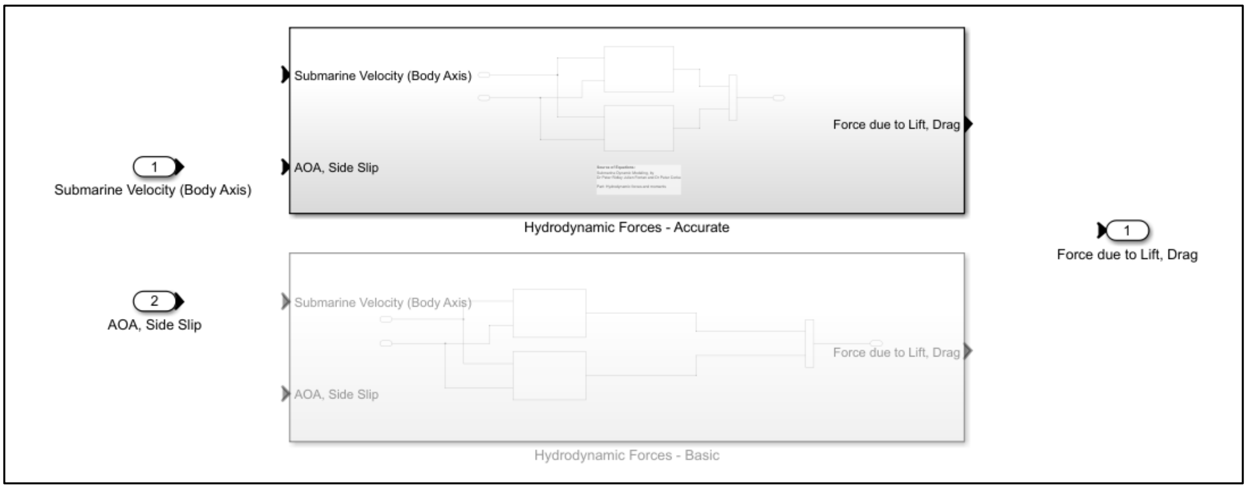

Figure 15

The Dynamic Solver subsystem receives the forces and moments returns the behavior of the AUV, as we saw in the previous conceptual model its core is the 6-DOF BLOCK that generates the position and angles of the AUV taken as a rigid leather. But this data must be processed to be integrated with the other subsystems, which is done through the POSTPROCESSING block. This layout can be seen in Figure 16.

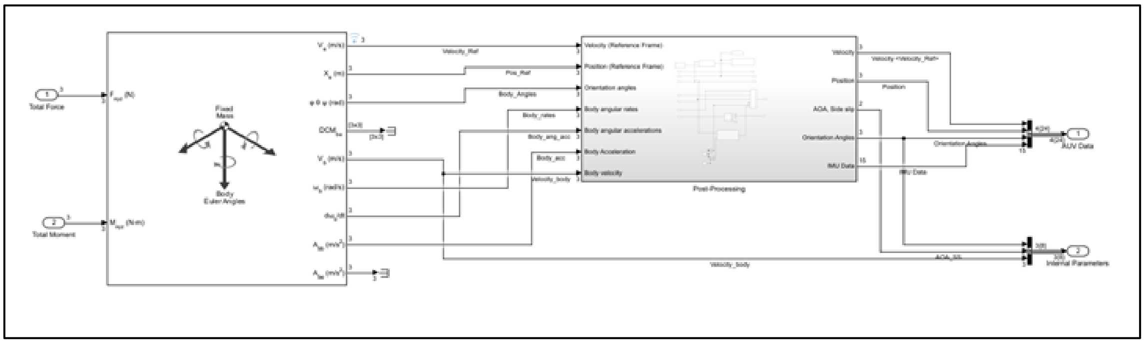

Figure 16

The Combine Forces and Moments subsystem performs the comparison of the desired input with the current situation of the AUV and acts as a PID controller that allows this model to be used within a simulation of the vehicle. This subsystem can be seen in figure 17.

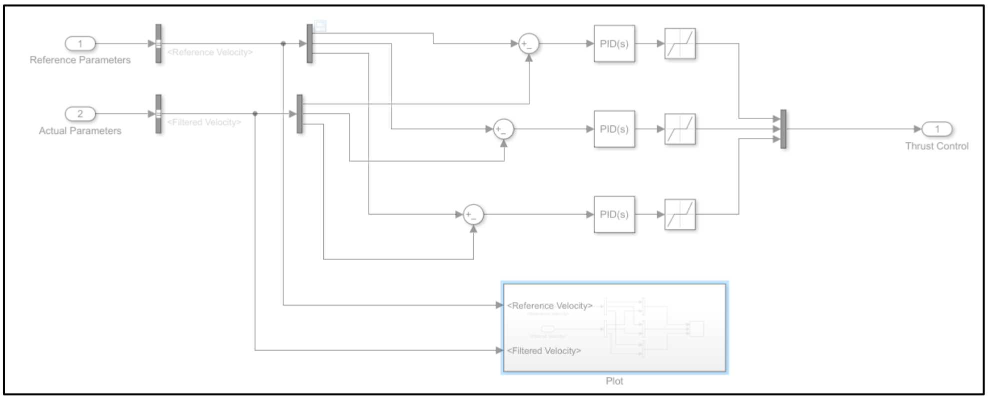

Figure 17

The utility of this model lies in the possibility of easily simulating the dynamics of the AUV within a simulation such as the one proposed by Yashodhar Veeralla. The reference model can be seen in the following figure

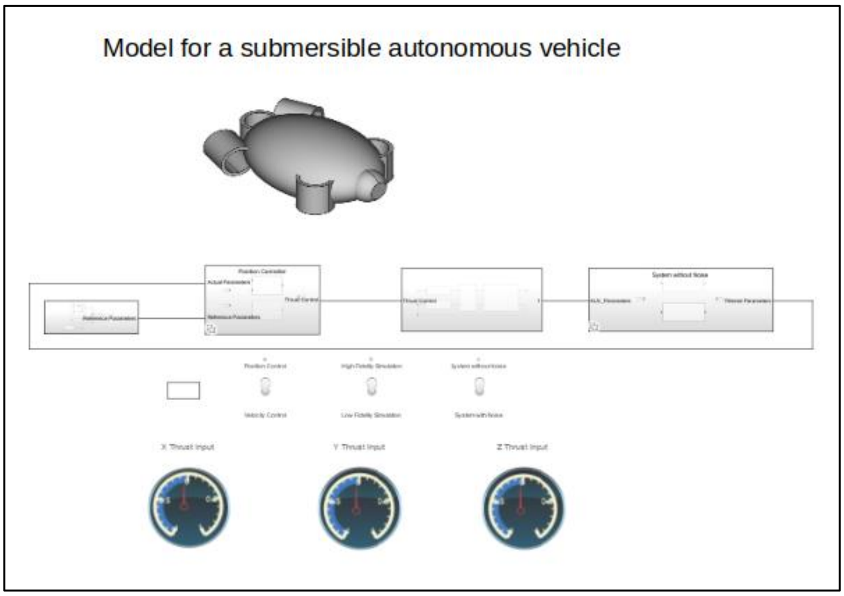

Figure 18

Here the proposed model is integrated with a subsystem of sensors and noise generators, which introduces disturbances from the real world, the Sensor data and State Estimation subsystem, which sends the information of the current parameters of the AUV to the Translation Controller subsystem which compares it with the reference parameters sent by the Translational Reference subsystem

4.- Some results obtained

The proposed model is subjected to a simulation for a trajectory without disturbances, the trajectory allows us to see how the parameters of the dynamic model of the AUV vary. The trajectory in a 3-dimensional system is shown in the figure.

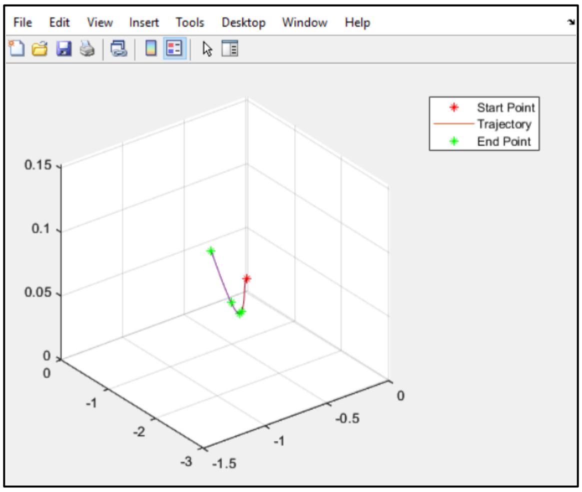

Figure 19

To see the dynamic behavior of the main variables of the vehicle, we monitor the signals of the Dinamic Solver subsystem, which receives the forces and the moments, returns the behavior of the AUV, through the 6-DOF BLOCK that generates the positions and speeds of the vehicle. The position and velocity signals for the trajectory shown in figure 19 are shown in figure 20. In figure 21 the thrust and velocity of the vehicle taken as a rigid body is shown. From the comparison between the thrust, the speed and the position, an over-damped behavior can be seen, where the inertial forces are clearly lower than those of coriolis and friction, despite the fact that considerations about them were minimized.

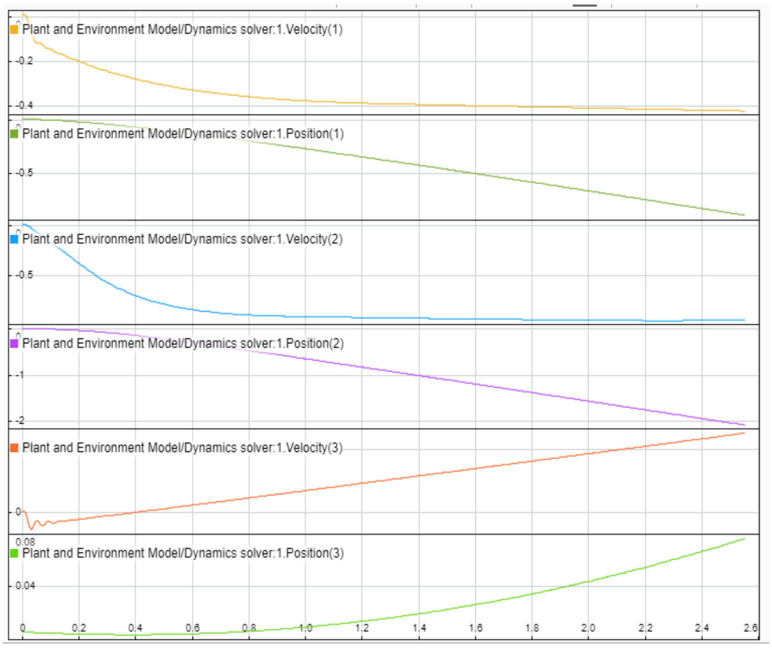

Figure 20

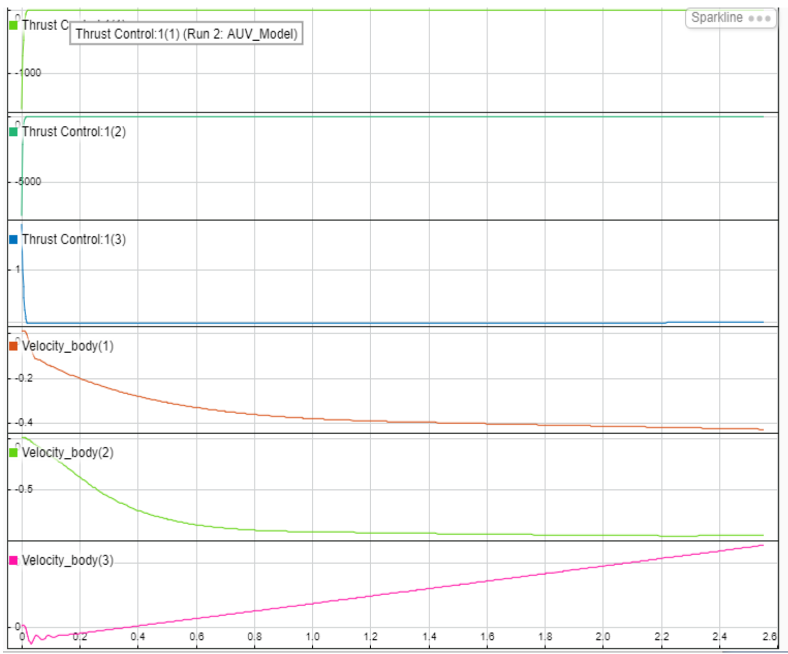

Figure 21

By introducing disturbances, the position and velocity signals for the trajectory shown in Figure 22 are shown in Figure 23. In Figure 24 the thrust and velocity of the vehicle are shown. As before the behavior is over-damped, and it can be seen that the disturbances only influence the start of the AUV's response to thrust forces.

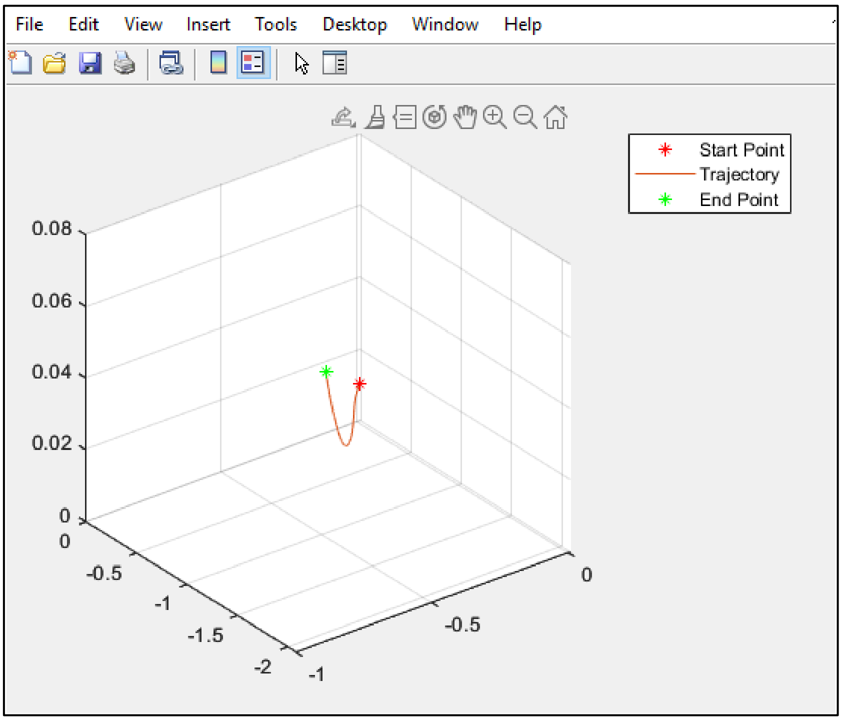

Figure 22

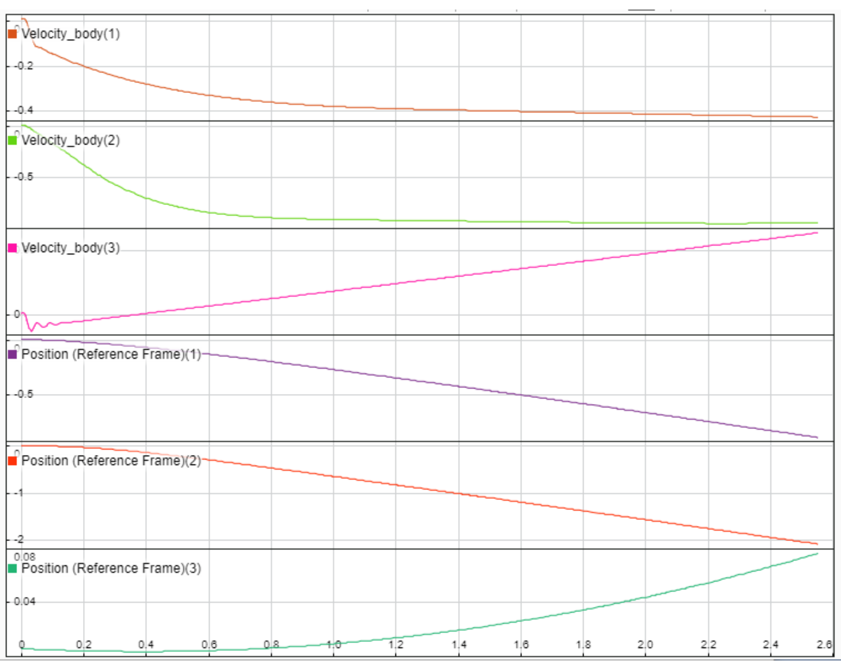

Figure 23

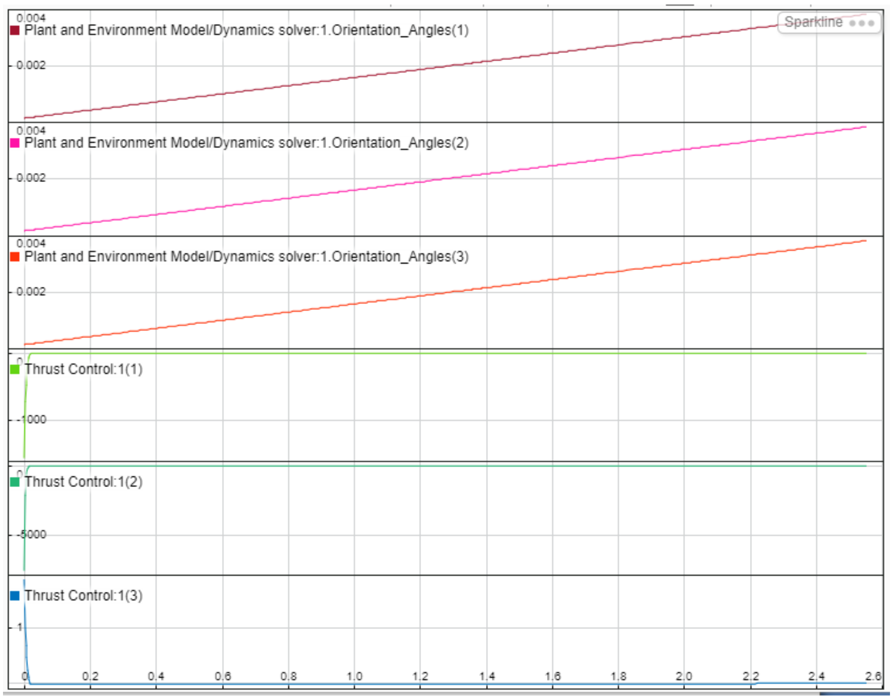

Figure 24

The simulation was complemented by obtaining other data. Figure 25 shows the effect of disturbances on the buoyant force.

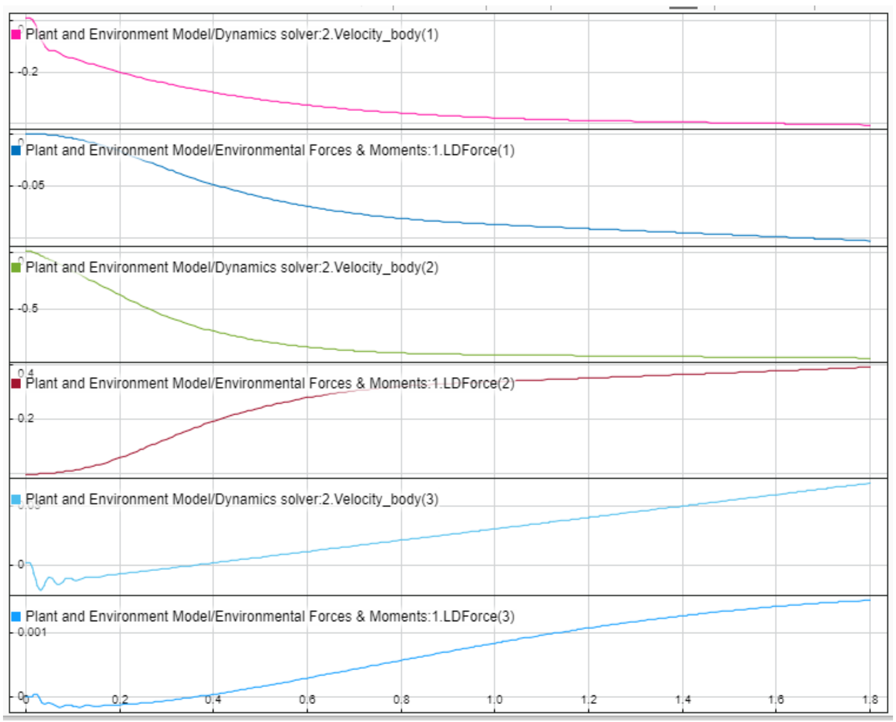

Figure 25

Figure 26 shows the relationships between the speed of the UAV and the displacement angles.

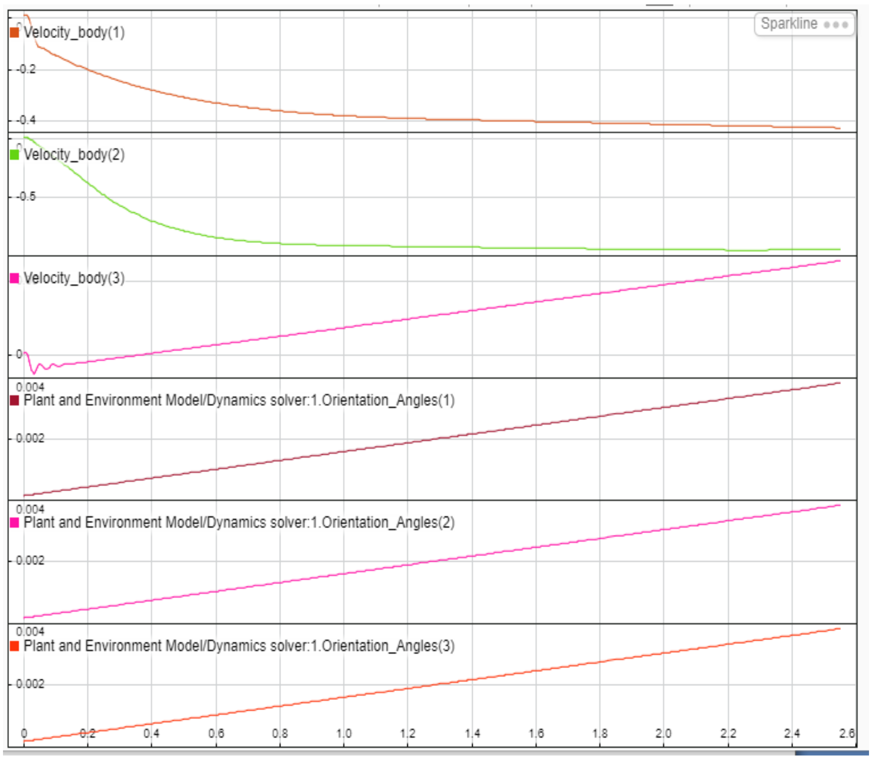

Figure 26

Figure 27 shows the relationships between speed and force in the presence of disturbances.

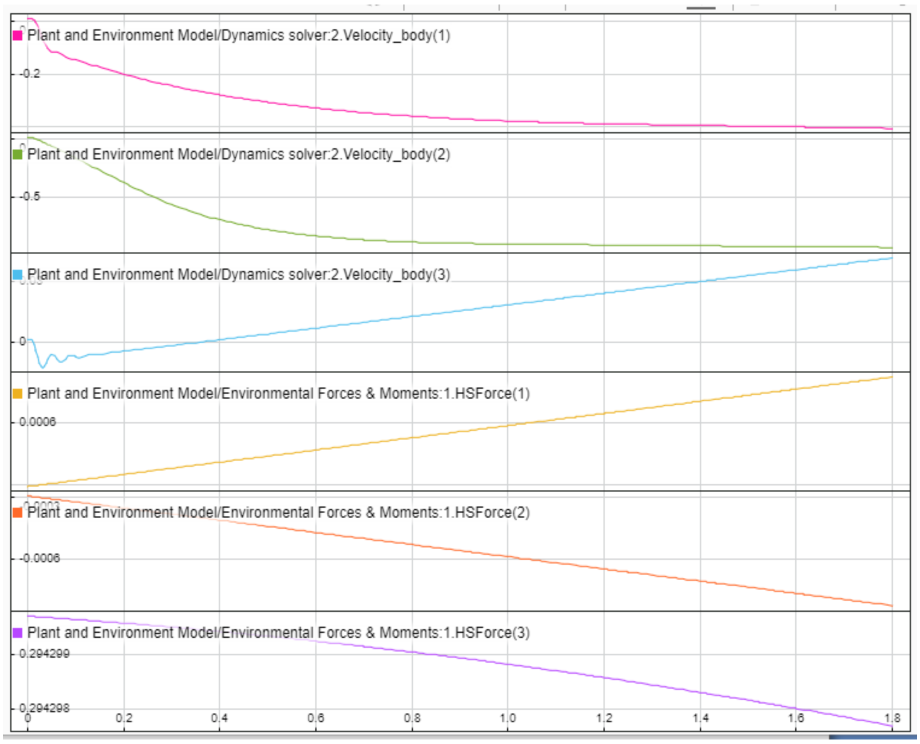

Figure 27

Figure 28 shows the relationships between the angular orientation and the acting forces without disturbances.

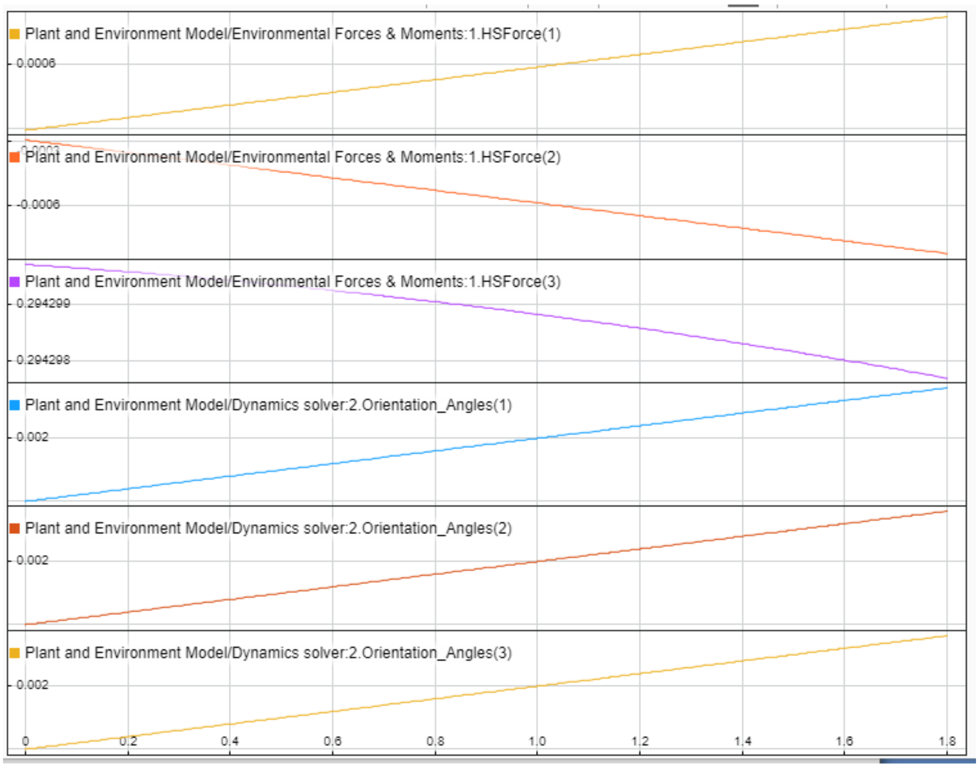

Figure 28

Figure 29 shows the relationships between the position of the UAV with respect to the axes and the displacement angles.

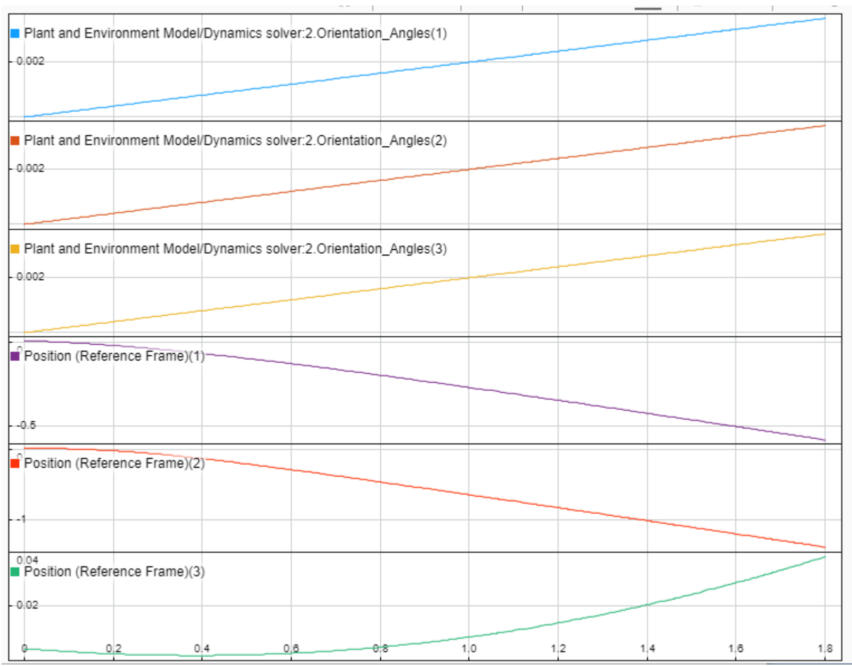

Figure 29

III Conclusions

5. Conclusions

The use of the methodology proposed by Veeralla, from the similarities between the dynamics of an underwater vehicle with the dynamics of airplanes, generated a useful simulation method to analyze the dynamics of the AUV considered as a system with 6 degrees of freedom. The analogy between the UAV and an airplane, using Simulink's AEROSPACE BLOCK SET, demonstrated that a description of vehicle dynamics could be obtained without resorting to complex calculations.

Acknowledgment

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