DEVELOPMENT OF METHODS TO EVALUATE SAFER FLIGHT CHARACTERISTICS

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ABSTRACT

The goal of the proposed research is to begin development of a simulation that models the flight characteristics of the Simplified Aid For EVA Rescue (SAFER) pack. Development of such a simulation was initiated to ultimately study the effect an Orbital Replacement Unit (ORU) has on SAFER dynamics. A major function of this program will be to calculate fuel consumption for many ORUs with different masses and locations. This will ultimately determine the maximum ORU mass an astronaut can carry and still perform a self-rescue without jettisoning the unit. A second primary goal is to eventually simulate relative motion (vibration) between the ORU and astronaut. After relative motion is accurately modeled it will be possible to evaluate the robustness of the control system and optimize performance as needed.

The first stage in developing the simulation is the ability to model a standardized, total, self-rescue scenario, making it possible to accurately compare different program runs. In orbit an astronaut has only limited data and will not be able to follow the most fuel efficient trajectory; therefore, it is important to correctly model the procedures an astronaut would use in orbit so that good fuel consumption data can be obtained. Once this part of the program is well tested and verified, the vibration (relative motion) of the ORU with respect to the astronaut can be studied.

INTRODUCTION

With the construction of the International Space Station in the near future, the risk to astronauts performing extravehicular activities (EVAs) rises greatly. Not only will the frequency of EVAs increase, adding to the possibility of a "break away", but the station will not be able to retrieve the astronaut if such an event occurs. This problem prompted NASA to develop the Simplified Aid For EVA Rescue (SAFER) maneuvering unit which would allow the astronaut to perform a self-rescue.

The SAFER pack is a self-contained unit which attaches to the Primary Life Support System (PLSS) on the space suit. It consists of 24 cold gas nitrogen thrusters which allow for six degree of freedom maneuvering. In addition, the SAFER unit also includes an Automatic Attitude Hold (AAH) system that nulls any undesired angular velocities. The AAH is initiated by the astronaut after the hand controller is deployed from its stowed location in the base of the SAFER unit. This will detumble the astronaut, at which point the station can be located and then the astronaut can translate back to the point of separation.

The SAFER pack was tested on STS-64 and performed admirably. However, in the future astronauts will be asked to carry Orbital Replacement Units (ORUs) and tools into position on the station, which will undoubtedly change the flight characteristics of the SAFER unit. An example of such a situation, where ORUs were carried by astronauts, occurred during the STS-76 mission where the astronauts carried and attached Mir Environmental Effects Payloads (MEEPs) to the Mir docking module (Figure 1). If an astronaut were to become separated from the station, the optimum situation would be to keep the ORU tethered. Keeping the ORU tethered would prevent the harm a jettisoned ORU could do to the station, as well as saving a valuable piece of equipment from drifting into space. The addition of these extra tethered units will obviously change the flight characteristics a great deal, affecting the ability of the astronaut to perform a self rescue. Not only will the mass offset affect the flight dynamics but also the vibration, or relative motion, of the ORU with respect to the astronaut will cause undesired effects. Relative motion was observed with the structure of the Manned Maneuvering Unit (MMU), which led to double the calculated fuel consumption. The SAFER unit was carefully constructed to avoid problems with relative motion, however, a small amount of relative motion was recorded on STS-64 (Figure 2). This motion was mostly attributed to the reaction of the astronaut's body with the space suit and movement of the limbs, and posed no problem for the superior SAFER control system. Unfortunately, with the addition of the tethered ORU this relative motion once more becomes important.

Currently, the only place engineers can run simulations is the Virtual Reality lab (VR lab) at NASA Johnson. The VR lab is an excellent training facility with full

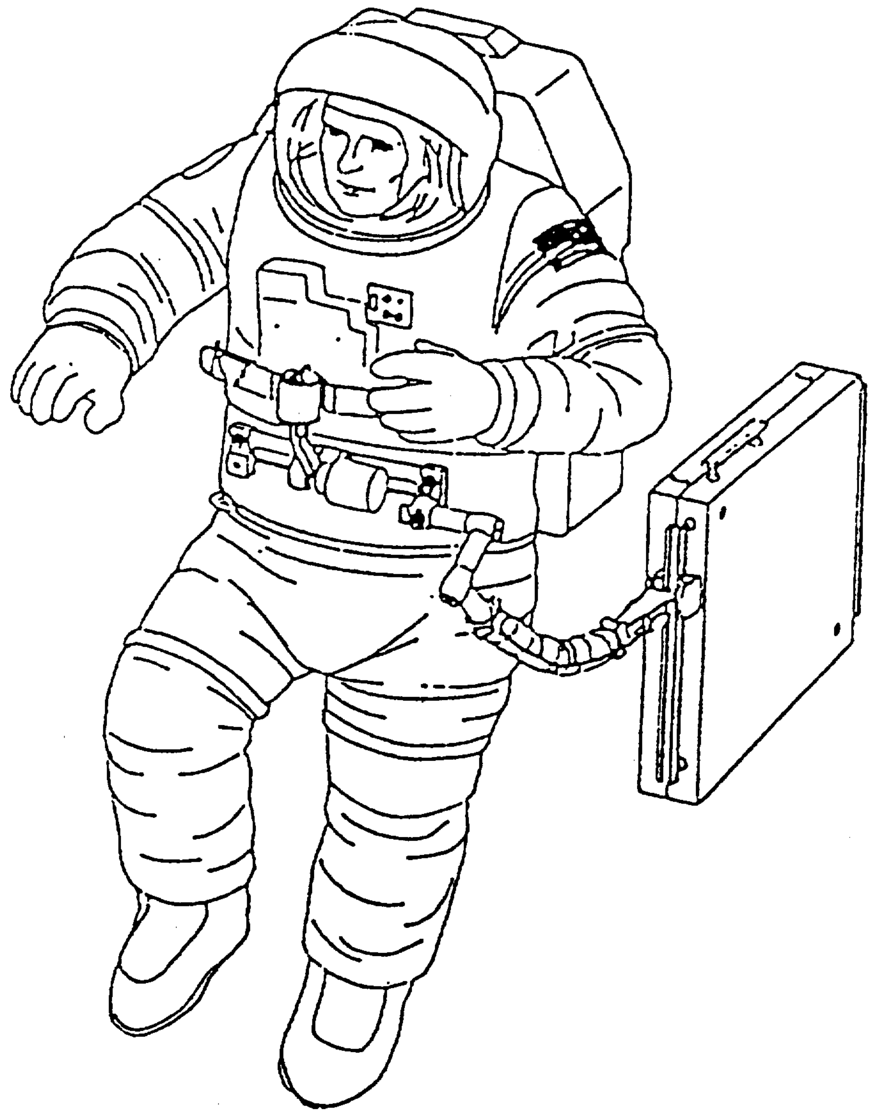

Figure 1. - Crewmember translating with a MEEP.

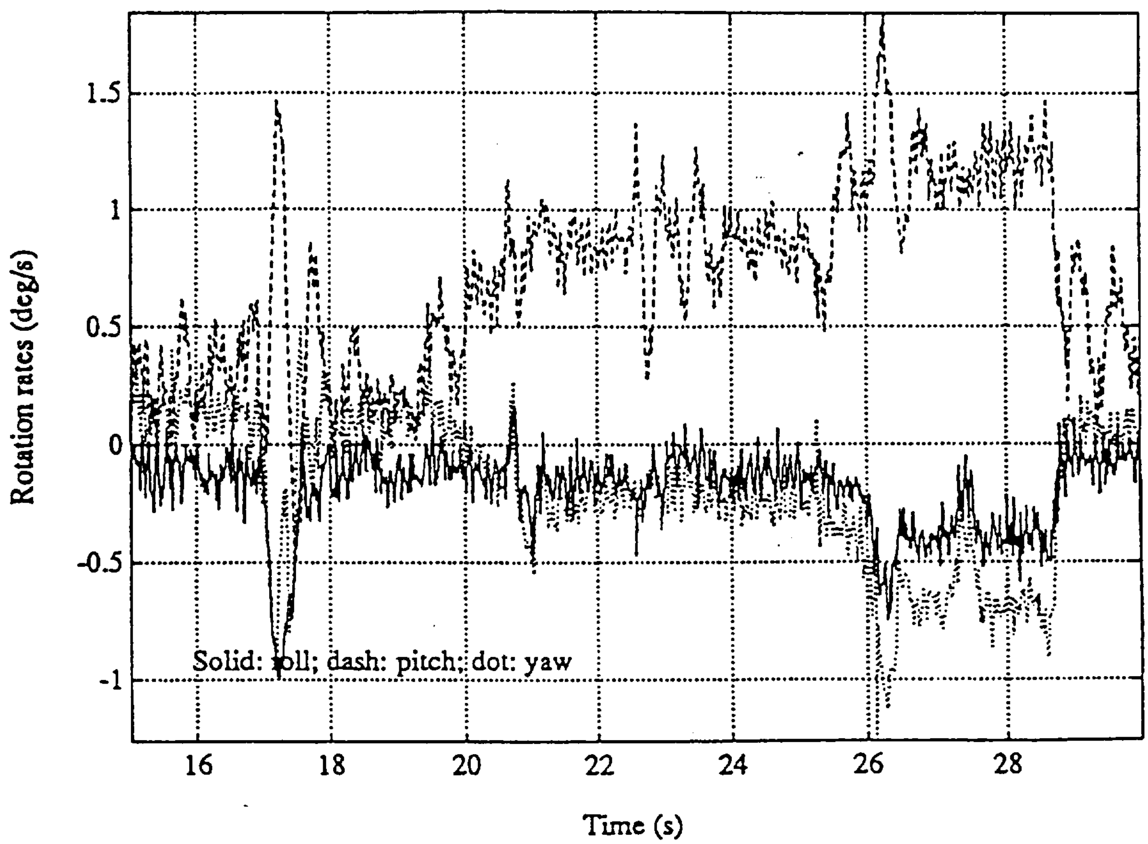

Figure 2. - STS-64 EV2 Engineering Evaluation positive x maneuver

animation and virtual reality capability. There are several problems with using the VR lab for the proposed relative motion study. First, the parameters in VR lab program are not easy to modify. Second, down time in the simulator reduces the amount of training time the astronauts receive. Finally, data from the runs is not easily accessible or directly comparable because commands to the SAFER simulation must be input manually, and human error can cause significant differences for one run to another. It is apparent that using the VR lab for engineering studies is not practical and would cut into valuable time for astronaut training. To alleviate the mentioned problems and to allow study of various engineering parameters, it is obvious that a new program will need to be developed.

For the effects of an ORU (including relative motion) to be studied accurately a standardized full self-rescue scenario must be modeled. Generally, a standardized full rescue scenario will allow quantitative comparison between runs. The most important comparison is fuel consumption, which will determine ultimately whether or not the astronaut will be able to return to the station. However, this program will also need to display angular velocity, attitude, velocity, and position information to evaluate control system performance. Of course, the program will be flexible enough for the user to easily vary several different parameters to evaluate and optimize performance.

SELF RESCUE

Modeling a full self-rescue scenario, starting with initial conditions at break away and finishing with return to the point of separation, is a critical part of simulation development. As mentioned previously, this scenario will allow accurate comparison between program runs. At first this may seem like an easy task; however, the difficulty arises with using only the limited visual clues available to the astronaut in orbit. Most likely the astronaut will not be able to use the most fuel efficient trajectory to return to the station. It is imperative to model the correct trajectory, as it will be executed in orbit, to obtain good fuel consumption calculations.

Modeling of a standardized self rescue procedure consists of several different phases currently based on separation rates observed in KC-135 tests and time estimates of procedures studied in VR lab simulations. The first phase is initial drift time. This takes into account the time an astronaut takes to realize what has happened, stow carried equipment, and deploy the SAFER hand controller. The next stage is the deceleration phase, which consists of the AAH counteracting any angular velocities that may be present from the separation. After angular velocities have dropped sufficiently (below the control system deadband) the astronaut must locate the station. Because of vision limitations and the position after the detumble, it is likely the astronaut will not immediately see the station, or know where it is located relative to the current position. Locating the station is achieved by performing, at most, a 360° pitch and then a 360° yaw. Somewhere in this range the astronaut will be able to see the station. Finally, the astronaut can translate back to the station. This is the most difficult part of the scenario to model, because orbital mechanics take effect. The most fuel efficient trajectory to use is described by the Clohessy - Whiltshire (CW) targeting equations. A CW burn is precisely initiated along a vector angled away from the Line Of Sight (LOS). However, the astronaut does not have precise velocity or position information. Finding the correct angle for the CW burn would be no more than a guess. Conversely, if the astronaut initiates a burn along the LOS, the only vector he has accurate information on, he ends up far from the station. An example of these orbital effects is shown in Figure 3; the outbound trajectory is solid, a correct CW burn dashed, and burn of the correct CW magnitude directed along the Line Of Sight (LOS) is dash dot.

The solution to this problem is to use inertial LOS targeting [3]. This uses more fuel than CW, but makes use of limited visual clues in orbit to get the astronaut back to the station. To initiate inertial LOS targeting a burn is directed along the LOS until desired velocity back toward the station is achieved. Then at regular intervals the astronaut checks the position of the station relative to the stars. If the station has drifted more than some allowable distance with respect to the stars, the astronaut applies thrust for some predetermined interval (based on mass) perpendicular to the LOS and in the same direction as the drift.

RESULTS

The first part of the simulation, up to the inertial LOS targeting, has been successfully programmed and reasonable comparisons can be drawn from the information. Figure 4, and Figure 5 display angular velocity for two different cases. Figure 4 was run with the mass properties for a large astronaut based on data obtained from training data. Figure 5 was produced by adding the mass properties of a 50 kg ORU to the astronaut mass properties. The initial break away conditions were angular velocities of 30 deg/s about each axis and 2.5 ft/s translation in the X direction. The 30 deg/s is a worst case value used by NASA to evaluate performance. In both cases the initial drift time, the time between break away and initiation of the AAH, was 30 seconds. Once the angular velocities have been significantly reduced, the astronaut will begin the process of locating the station by means of a 360° pitch and 360° yaw. To keep the total drift time, time between initial break away to start of translation, to a minimum the "recommended" time to complete the search procedure has been set at about 50 seconds. This leaves 25 seconds for the 360° pitch maneuver and the other 25 seconds for yaw, which corresponds to maintaining an angular velocity of approximately 15 deg/s for 25 seconds. Examining the figures, it is apparent that the graphs are quite similar, due to the standardization of the self-rescue routine. With all parameters controlled it is possible to accurately compare the fuel consumption between the two runs. The fuel consumed in Figure 4 is 0.2679 kg while that of Figure 5 is much greater at 0.7972 kg., which is as we expected. The farther the center of mass is displaced from the designed center of mass, the more the thrusters, which are no longer optimized, must work to perform maneuvers.

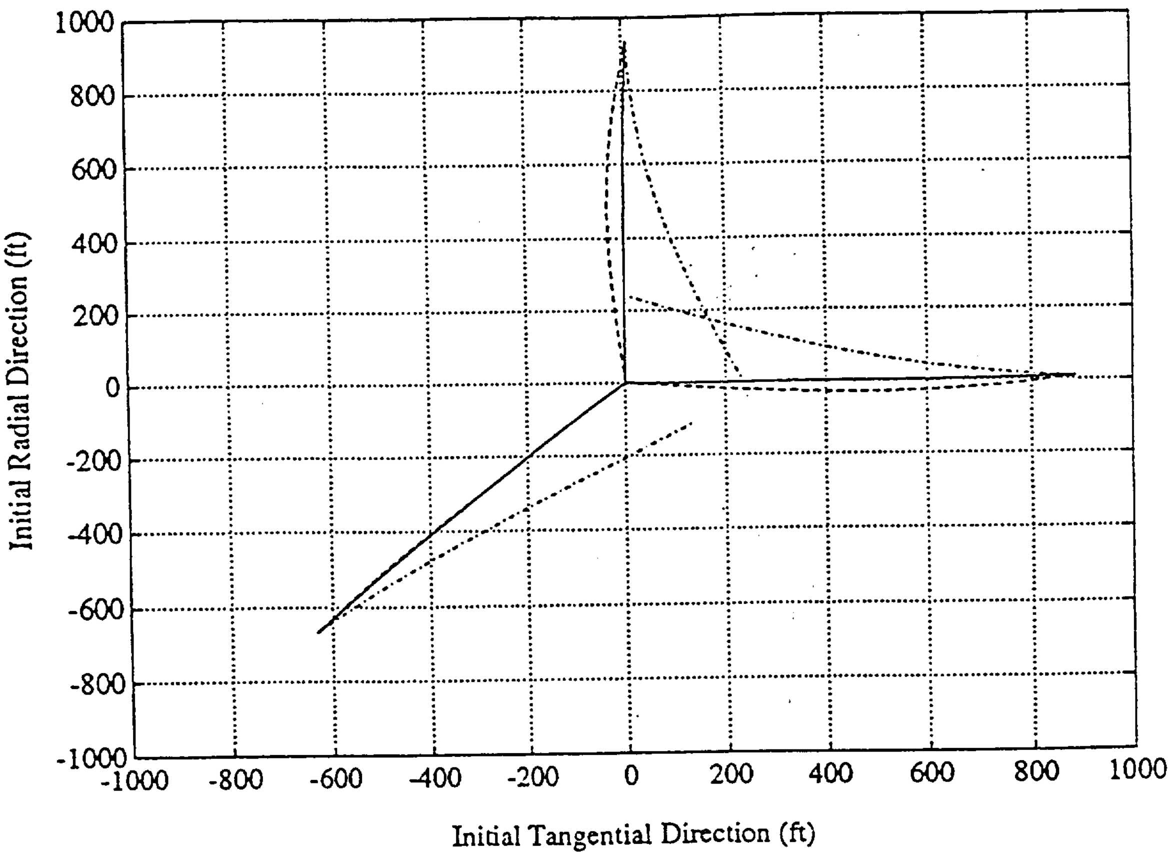

Figure 3. - Trajectories in non-rotating coordinates

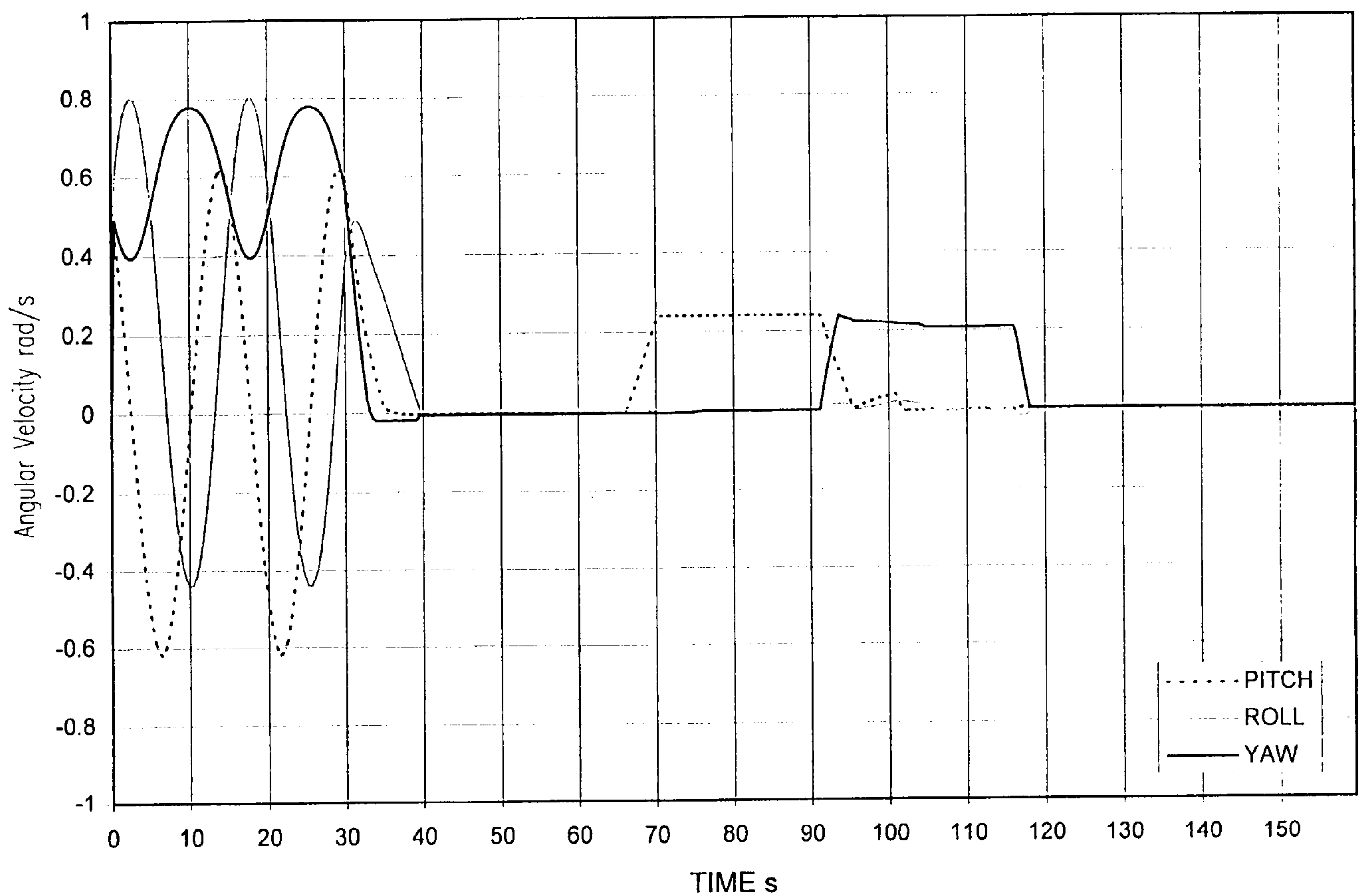

Figure 4. - Angular rates for an astronaut without an ORU

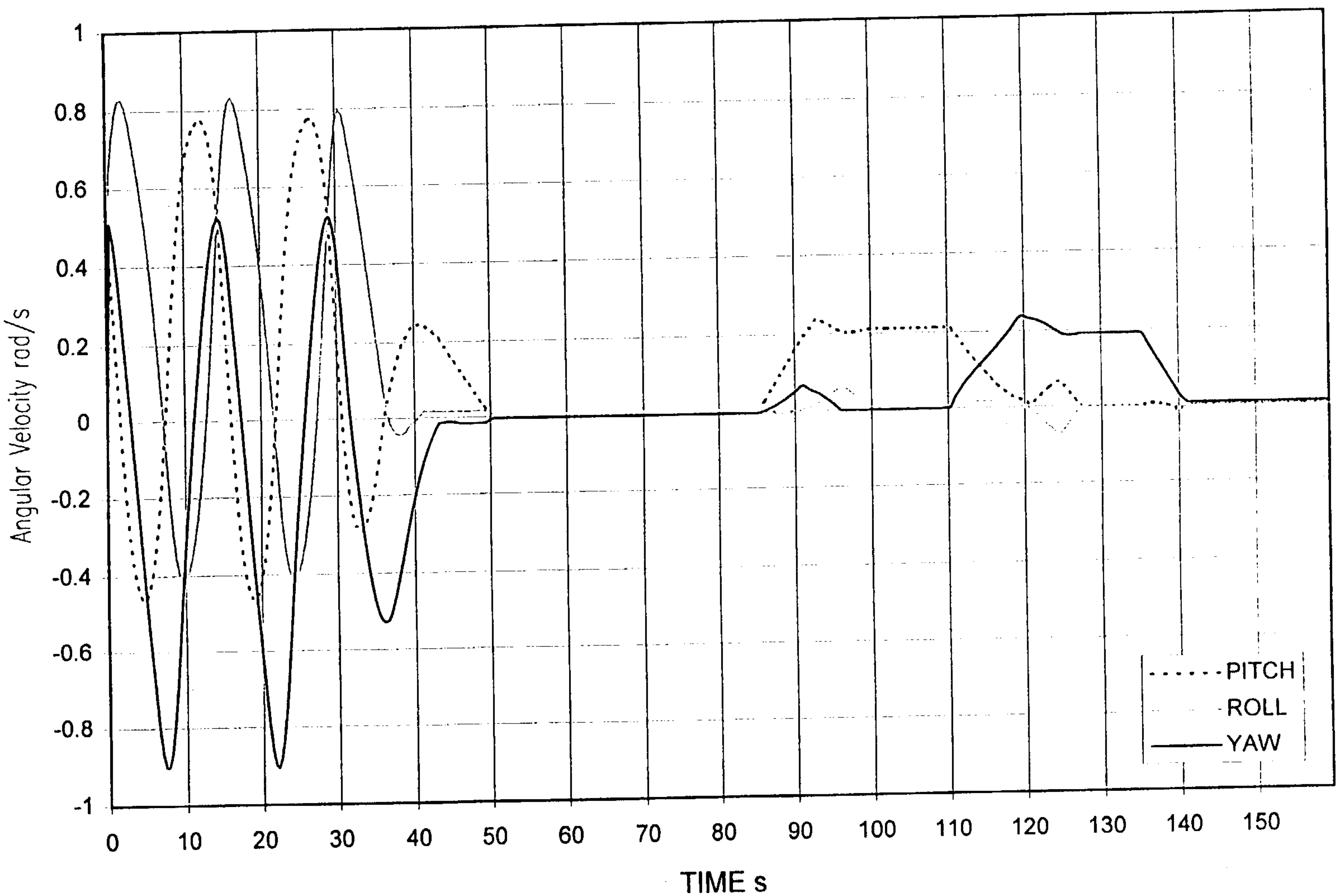

Figure 5. - Angular rates for an astronaut with a 50 kg. ORU

A closer examination of the angular velocities for the station search procedure reveals that the effects of cross-coupling are clearly present in Figure 5; these effects obviously cause the control system to use more fuel.

These cases are very simple, but illustrate the capability that the finished program will give to the engineer. After seeing the effects of cross-coupling in the angular velocity plots the engineer may decide that a more aggressive control system will need to be designed. The fuel consumption figures will also allow the engineer to make recommendations on the maximum mass that the astronaut can safely carry. The mass properties used for Figure 5 were based on an ORU carried to the left of and behind the astronaut. By simply typing in a new ORU location, the engineer will be able to find the optimum, or most fuel efficient, position of the ORU.

CONCLUSION

Based on the work thus far it is evident that a portable, flexible program could be used quite effectively to analyze SAFER flight characteristics. Based on the preliminary data, NASA has expressed interest in continuing code development. By the end of this year the modeling of relative motion should begin; however, good data on the effects of ORUs on SAFER dynamics will have been obtained. Modifying these values by some safety factor, will give moderate accuracy and assure safety of the astronauts, until relative motion can be researched in more detail.

As construction of the International Space Station draws near, it will become very important to find the limits of the SAFER unit so that recommendations on ORU mass and position can be made. As more research is conducted it will be possible to understand the causes of relative motion and model them with increasing accuracy. To verify this final stage of the program it is inevitable that empirical data will need to be collected. Air bearing floor and KC-135 tests seem the most likely candidates to obtain precise results. Until this empirical data can be collected, a good routine can be developed using estimated quantities. As new data is uncovered the simulation will be refined.

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