PHYSICS 3300 Case Study - An Accident in Space Part 1

1 Overview

On June 25, 1997, during a manually controlled docking test between an unmanned supply ship and the Russian space station, *Mir*, the supply ship collided with the Spektr module of Mir, tearing through solar panels and breaching the hull of the Spektr Module. The resulting loss of atmosphere and the induced tumbling of the space station threatened the lives of the three crew members aboard. The crew were ultimately able to seal off the Spektr module and stabilize Mir.

Read the assigned article on the Mir Space Station and the 1997 accident involving the Spektr Module. The course pages list several Youtube interviews and analyses of the accident that will give you some historical perspective on this event. A related depressurization (often called a 'depress') occurs in the move *The Martian*, though the physics is not accurate in that portrayal.

The purpose of this Case Study is to investigate the physics of effusion as it applies to spacecraft depressurization. We will want to be able to correlate the time it takes for the air to rush out of a hull penetration of a given size, to understand the dynamics of effusion in terms of the forces involved, and to determine what sorts of procedures should be in place in order to react efficiently to survivable hull penetrations. In doing so, you will reproduce the crew's calculations, which determined the size of the hull penetration based on measurements of the air pressure drop and the time between impact and the sealing off of the Spektr module from the Mir.

An interesting side note is that the American crew member onboard Mir at the time of the accident, Michael Foale, is an astrophysicist by training. His background in physics was essential to solving the cascade of problems resulting from the collision. With no power on the ship, navigation and control systems were down after the impact. Foale estimated the rotation rate of the station by measuring star motion across the viewing port. He was able to relay estimates of tumble rate and orientation to the ground controllers who then calculated the thruster firings necessary to stabilize the station.

2 Technical Data

The Mir Space Station consisted of several cylindrical modules connected to a cylindrical "base block." The total pressurized volume of the station including all modules at the time of the accident was 350 m^3. The air pressure was maintained at 14.7 psi.

The Spektr module, a cylinder with length 12 m and diameter 4.4 m, had a total pressurized volume of 62 m^3. The Spektr module was connected to the base block by way of a circular hatch that was 1.0 m in diameter.

At the time of the accident and resulting Spektr module depress, the two Russian member of the three-person crew were in the base block of the Mir station, while Michael Foale was in the Spektr module, where his living quarters were. After the impact, Foale quickly moved from Spektr to Base Block and began work to seal off the leaking module from the rest of Mir and to assess the severity of the problem. The master alarm indicated that the crew had 18 minutes of useful consciousness remaining in which to solve the problem before air pressure dropped below survivable levels.

Solar panels on the Spektr module supplied 40% of station electrical power through thick cables that passed through the hatch connecting the Mir base block to the Spektr module. Some of those cables did not have quick-disconnect fittings and had to be cut using a knife in order to close the hatch. Once free of cables, the crew were unable to pull the hatch closed because of the force of escaping air. They eventually located a hatch cover on the base block side that could be pushed into place and sealed with the air pressure difference between the base block and Spektr. From the time of the collision to the time of a hatch seal, 14 minutes had elapsed. In that time the pressure in the base block had dropped from 760 mmHg to 693 mmHg.

3 Analysis

1. In your discussion group, make a rough diagram of the Mir base block and Spektr module and indicate the volumes of each (for the purposes of this case study, it doesn't matter that there were other modules attached to the base block as long as you account for their contributions to the total air volume).

2. Using the analysis of problem 1.22 and the data provided above, develop a formula for determining the area A of the hull breach in the Spektr module. Express your formula only in terms of the known data and thermodynamic constants. Assume that the temperature during the effusion event remained roughly constant at $T = 300K$.

3. Use a spreadsheet to setup a calculation for the hull breach area (in cm^2). For the data given, what is the diameter of the hole in the Spektr module?

4. The event report and subsequent interviews suggest that the crew had difficulty closing the 1.0 m diameter hatch on the Spektr-side of the node by pulling it shut against the escaping air. Use your spreadsheet to determine the initial force on the hatch.

5. When a hatch cover in the base module was located and pushed into the hatch, sealing it, the Spektr module continued to depressurize. Use your spreadsheet to calculate how long it took for the module to depressurize to vacuum (assume this time is roughly given by the characteristic time τ where τ is defined in problem 1.22). What force is exerted on the hatch cover when the Spektr module is completely depressurized and the base module has been brought back to STP?

6. After the accident, the engineering ground response team estimated that the crew had longer than 18 minutes to address the situation, but not much longer. Using your spreadsheet model, estimate how long the crew would have survived before suffocating if the hatch had not been sealed. In aviation and space physiology, the time of useful consciousness (TUC) is an estimate of the time a resting, healthy person can remain conscious at various altitudes and pressures. Such tables are easily found on the web and you should use these data as a resource in addressing this question.

7. It took 14 minutes to seal the hatch. Had the hull breach been larger, the crew might not have survived. A post-accident analysis resulted in several recommendations for future station protocols. One such recommendation was that all cables passing between modules should have quick-connect fittings to allow easy disconnections in an emergency hatch closure. Investigators also discussed the survivability of such events under different atmospheric concentrations of O_2. Had the partial pressure of O_2 been higher than 20% would the crew have had a longer time to address the problem? What additional complications would have resulted had this been the case?

4 Submission

Submit full narrative responses to each question above with all governing equations symbolically derived and all constants and variables explicitly defined. Include the formatted spreadsheet used in your analysis. While you can work together to understand the problem, your writeup should be entirely your work. Where you have received guidance or useful ideas from classmates, cite them by name and identify the contribution or insight they provided.

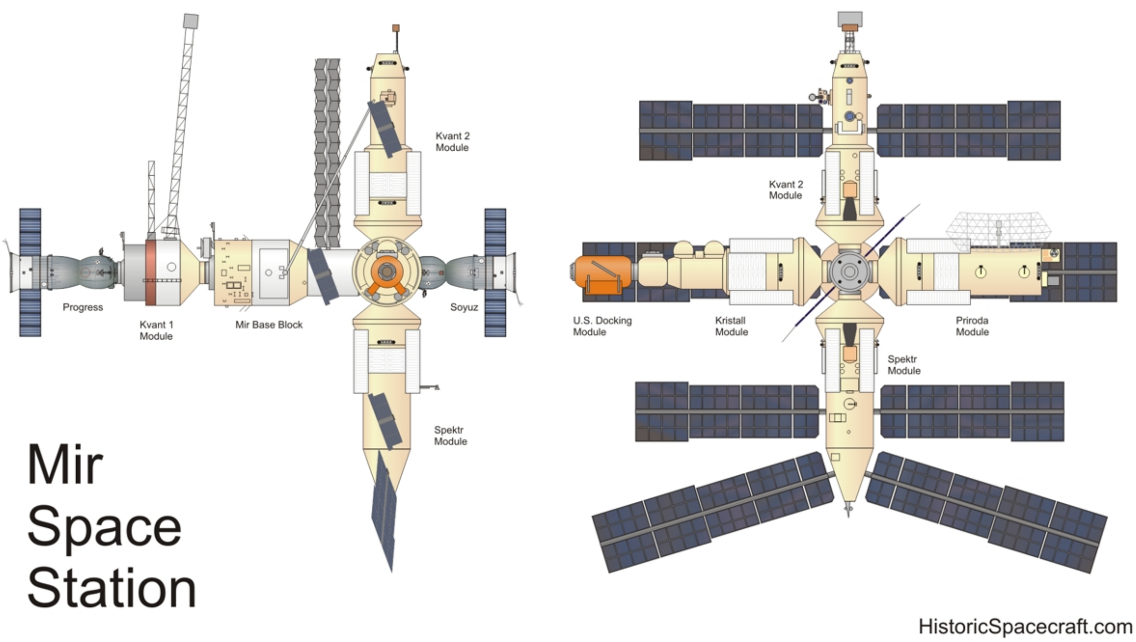

Figure 1: Mir Space Station Diagram with Spektr Module.