National Cheng Kung University
Department of Mechanical Engineering
NCKU

Introduction to Multi-Core CPU and GPU Computation

Major Group Assignment 2015

Progress Report A – Due: 28th Oct, 2015 **Progress Report B – Due: 2nd Dec, 2015.**

Final Report - Due Date: 11th Jan, 2016 **Oral Presentation – Due Date: 13th Jan, 2016.**

Group members: 3 students per group (maximum)

Background

The Boeing X-37 is a newly developed reusable unmanned spacecraft currently being used by the United States Air Force for orbital space missions. Early designs for the X-37 began in the late 1990's at NASA before being transferred to the department of defence. In 2004, the project became classified and in recent times several test launches have been successfully completed. The aerodynamic design of the X-37 was based on the design of the US Space Shuttle. An image if the X-37 is shown below in Figure 1, together with the 3D model we will be using for this project. The vehicle is designed with withstand high speed atmospheric re-entry with hypersonic flows in excess of Mach 8. During re-entry, the vehicle's engines will not be engaged and the vehicle will be flying with an angle of attack of approximately 40 degrees. At these speeds, a detached bow shock will form around the vehicle with the stagnated flow behind the shock resulting in high temperatures.

Figure 1: (left) Image of an X-37 prior to launch in 2010, (right) the simplified IGS and STL model which we will be using during this assignment.

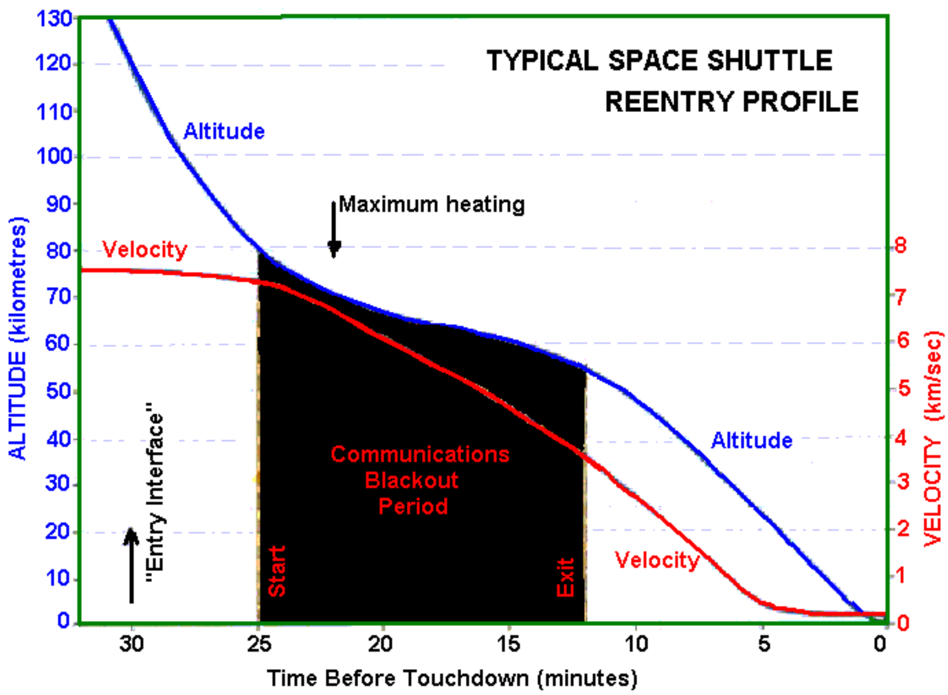

Figure 2: Diagram showing a typical re-entry profile for a space shuttle mission.

Assuming the flight plan of the X-37 follows that of a typical space shuttle, as shown in Figure 2, the maximum heating conditions occur at an altitude of approximately 70 km and a velocity of 7000 m/s. The goal of this assignment is to compute the flows around the X-37 at this altitude and velocity.

Assignment Tasks

1) Each group will be given a logbook. This logbook will be used to keep a regular record of (i) project progress, (ii) group member contributions, (iii) mathematical derivations, and (vi) code snippets and debugging efforts. Each group will show me the logbook 3 times during the project: (i) 28th of October, (ii) 2nd of December, and (iii) 11th of January.

2) Each group will prepare a project timeline using a Gantt chart as shown in Figure 3. Each action item should be clearly listed, together with an expected start and completion date. Seeing as each group will have 3 members, each student's work items should overlap with coincide with the others. Students should show me their project timeline during their 1st progress report on the 28th of October.

3) The students should present a 5 minute PowerPoint presentation describing their progress. There will be two such progress reports – one on the 28th of October, and a second report on the 2nd of December. The items required for each progress report are shown in Table 1.

4) Students should write a C/C++ code to solve the one dimensional shock tube problem using OpenMP parallelization. Details of the problem can be found online at the address below. Students should show profiles of temperature, pressure and speed when using 200, 1000 and 5000 cells after a dimensionless simulation time of t =0.2. Students should also show the parallelization efficiency of the problem using 2, 4, 8 and 16 CPU cores. (https://en.wikipedia.org/wiki/Sod_shock_tube)

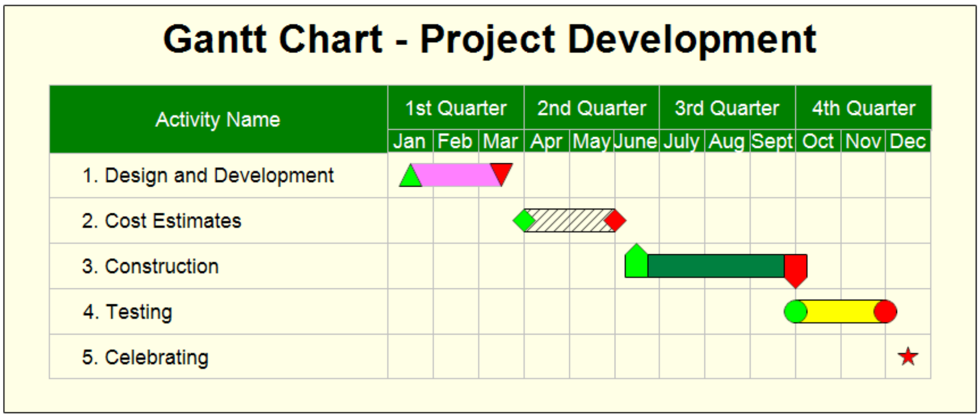

Figure 3: Sample GANTT chart showing the planning phase of a project.

(tasks, continued)

5) Based on the solver developed in part (4), students should write a two dimensional compressible CFD solver to solve the shock bubble interaction problem shown in Figure 4. Students should write the code to be parallelizable using OpenMP and, if possible, GPU with CUDA. Students should show results after t = 0.8 using computation grids of 200x100, 400x200 and 800x400. Parallelization efficiency should be shown using 2, 4, 8 and 16 cores. This results should be shown during the 2nd progress report on the 2nd of December.

6) Using the CFD solver developed in part (5), students should write a three dimensional compressible flow solver to calculate flow around the X-37. This code should employ both OpenMP and CUDA for GPU parallelization. Students should report their results using at least 1 million computational cells. These may be Cartesian cells (i.e. a structured, rectangular grid), an AMR mesh or an unstructured tetrahedral grid. Results should be shown after the flow has reached a pseudo-steady state. The X-37 should have an angle of attack of 40 degrees, with an inflow velocity of 7000 m/s with a pressure and density corresponding to that of air at an altitude of 70 km.

7) Students should prepare a professional engineering report into the simulation of the X-37 as completed in task (6). This should include (i) a description of how the group solved the problem, (ii) a comparison of the planned project timetable (item 2) to the actual measured work progress, (iii) a flowchart showing your computational method, (iv) the derivation of the mathematical approach used for the computation, (v) the results – X, Y and Z velocity, temperature and pressure profiles for several slices of the 3D geometry, (vi) discussion into the parallel performance, and (vii) conclusions and discussions into the effectiveness of the group to complete the project.

8) Students should prepare a professional presentation which will be delivered to the class on the 13th. This presentation can be delivered in English or Chinese, and will discuss the contents contained in the final report. The presentation should run at least 10 minutes, with a key focus on the final result graphs (velocity, temperature, etc) and the parallel performance.

Important

If the students have any questions, they can approach me at any time. Time will be allocated during the class prac session on Wednesday afternoon for completion of this assignment, but significant time will be needed outside of class time if this project is to be completed.

Item	Due date	Description
Project Gantt chart	First Progress Report 28th of October	Use Excel to create a Gantt chart which clearly show which items are to be completed, by whom and by which date. Several items should have already been completed by this phase.
1D Shock Tube Simulation using OpenMP	1st Progress Report 28th of October	Show the results from the one dimensional shock tube problem.
2D Shock Bubble simulation using OpenMP / GPU	2nd Progress Report 2nd of December	Show the results for the two dimensional shock bubble interaction problem.
3D simulation of hypersonic flow around the X-37	Final Report 11th of January	Show the X, Y and Z velocity, temperature and pressure results for the 3D flow simulation around the X-37.

Table 1: Key work items and due dates for the major group assignment.

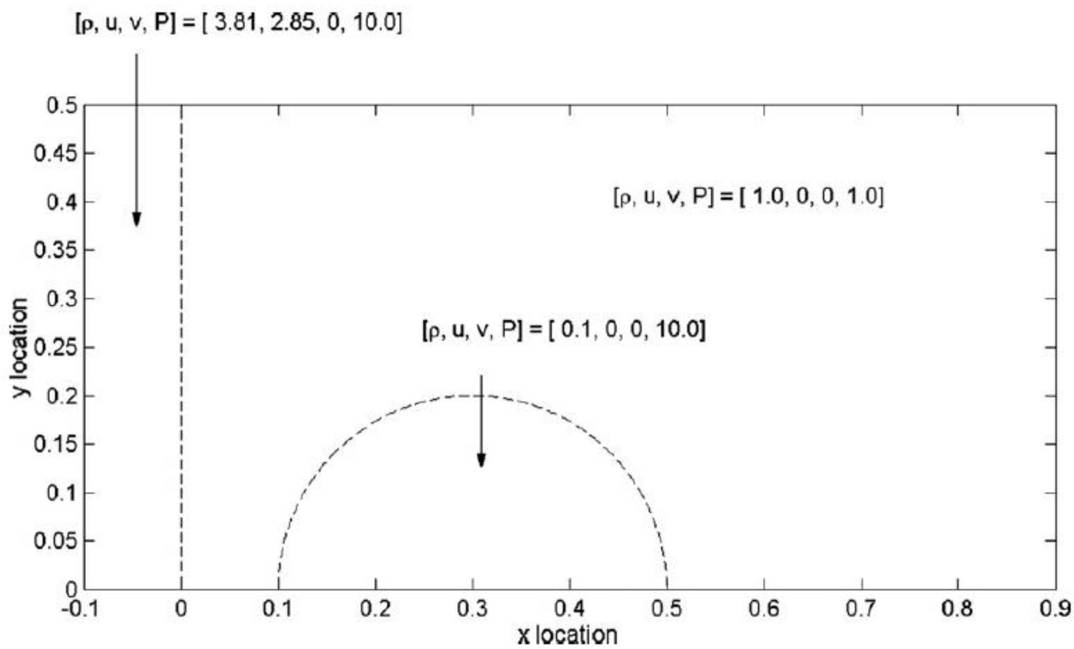

Figure 4: 2D Shock Bubble Interaction problem