LTA 17

NASA - AMATYC - NSF
Project Coalition

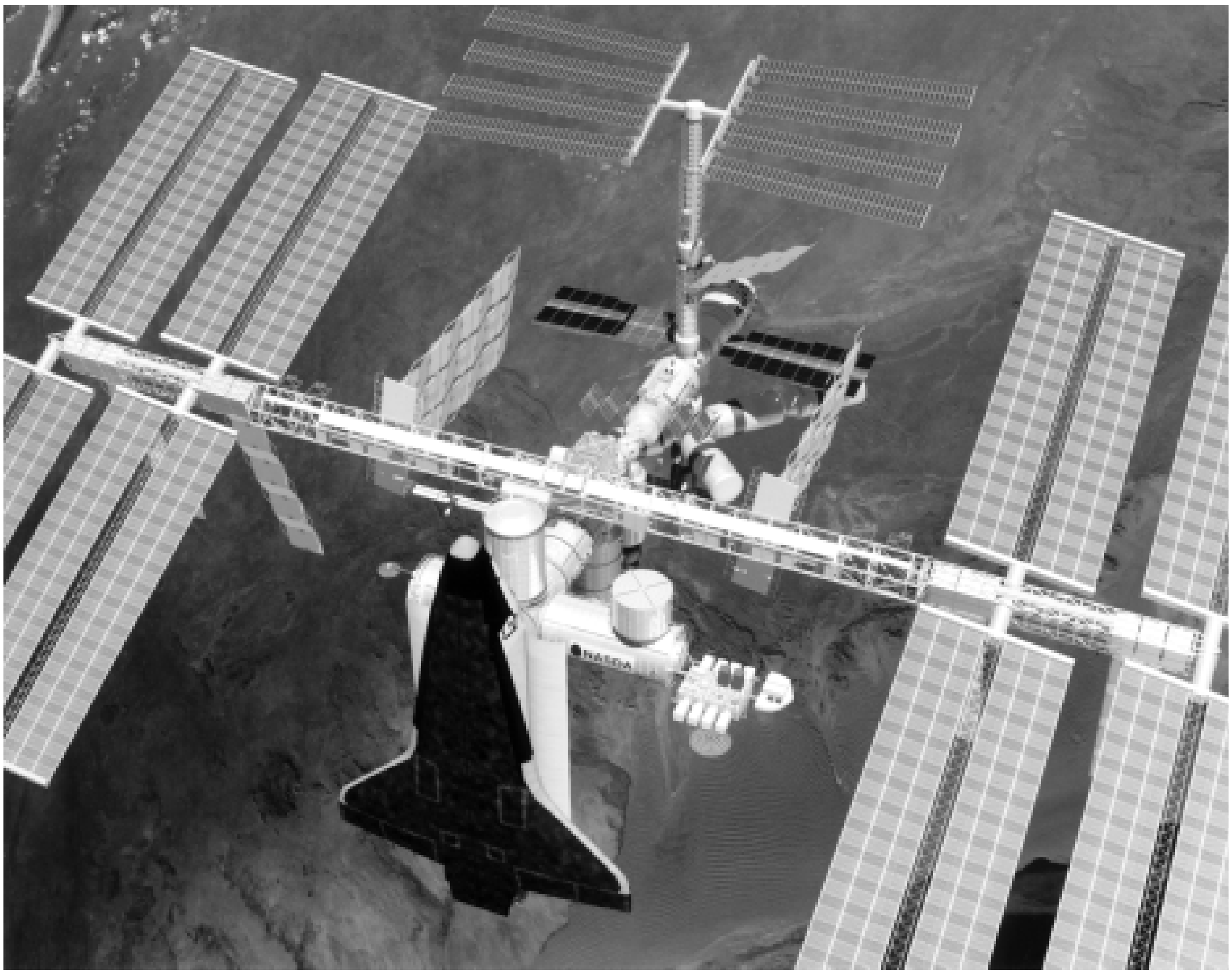
Kennedy Space Center

Ground Tests of the Computer Start-Up Systems for the International Space Station

Mathematics for Engineering Technology

Electrical
Space
Systems

Capital Community College



A Space Shuttle is docked to the International Space Station in this computer-generated representation of the U.S.'s international cooperation in space.

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Mathematics for
Electrical Engineering Technology
Space Engineering Technology
Systems Engineering Technology

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Chris Oehrlein has been teaching in the West Virginia and Oklahoma Community College Systems since 1995. He was instrumental in establishing the West Virginia AMATYC Affiliate as well as becoming its President-Elect and President. He has also served as President of AMATYC's Oklahoma Affiliate (1999 - 2001). Chris has been involved in writing and reviewing grants that reflect his interest in introducing computer software and more realistic modeling into all mathematics courses and other courses with quantitative components.

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Sherri Carlson has worked for NASA as an avionics engineer for 13 years. She has had the privilege of working on both the Space Shuttle and International Space Station programs. Currently she is working to develop and implement space vehicle health technologies to allow more autonomous operation of spacecraft, specifically the X-34 sub-orbital space-plane. Sherri is also an educator and a former physics teacher. Her goals include encouraging her community to embrace the benefits of the American Space Program and sparking the interest of local students to pursue careers in engineering and the sciences.

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Introduction

The United States and its partners, Japan, Canada, Italy, Belgium, Netherlands, Denmark, Norway, France, Spain, Germany, the United Kingdom, and Russia, are currently engaged in the largest cooperative scientific program in history, the building and operation of an International Space Station. Each of the partner countries will be building different components of the Space Station. The launch of the first elements will occur late in the 20th century and the Space Station will be operating with full crews on board shortly after the year 2000.

The Space Station will be 290 feet in length with a wingspan of 361 feet. The weight of the Space Station in orbit will be 831,000 pounds. Due to its size the Station will not be launched as a single unit. Instead, individual components of the Station will be launched separately as they are completed, and the Station will be fully constructed in space. The Space Station will then orbit the Earth at 220 miles above sea level and will support permanent human habitation for conducting research and science experiments. Power will primarily be provided to the Space Station through solar panels located on its wings. Normally, there will be a crew of six people living on the Space Station. There will be frequent changes in crew size and personnel.

The International Space Station will be a great laboratory for scientific research. Because of the absence of gravity in space, researchers can study materials and processes that could not be studied in the normal gravity of Earth. This research will lead to increased applications in many fields such as physics, materials science and communications. Additionally, the Space Station will be a laboratory for a number of research questions in the health sciences. Research on the Space Station will build on the proven work already performed on other space programs. However, in contrast to experiments on the Space Shuttle which are limited to roughly two-week intervals, work on the Station can continue as long as needed.

A process that requires extended time in space is the growing of large protein crystals. The growth of such large crystals is a slow process which cannot be done on Earth because the size of the crystals is limited by gravity. These larger crystals, which are much easier to study and understand than smaller counterparts, can be grown in the gravity free environment of the Space Station. A better understanding of protein structure may in turn provide new insights into cancer research, diabetes, emphysema, and immune system disorders. The Space Station will also help NASA further the process of scientifically exploring the rest of the solar system.

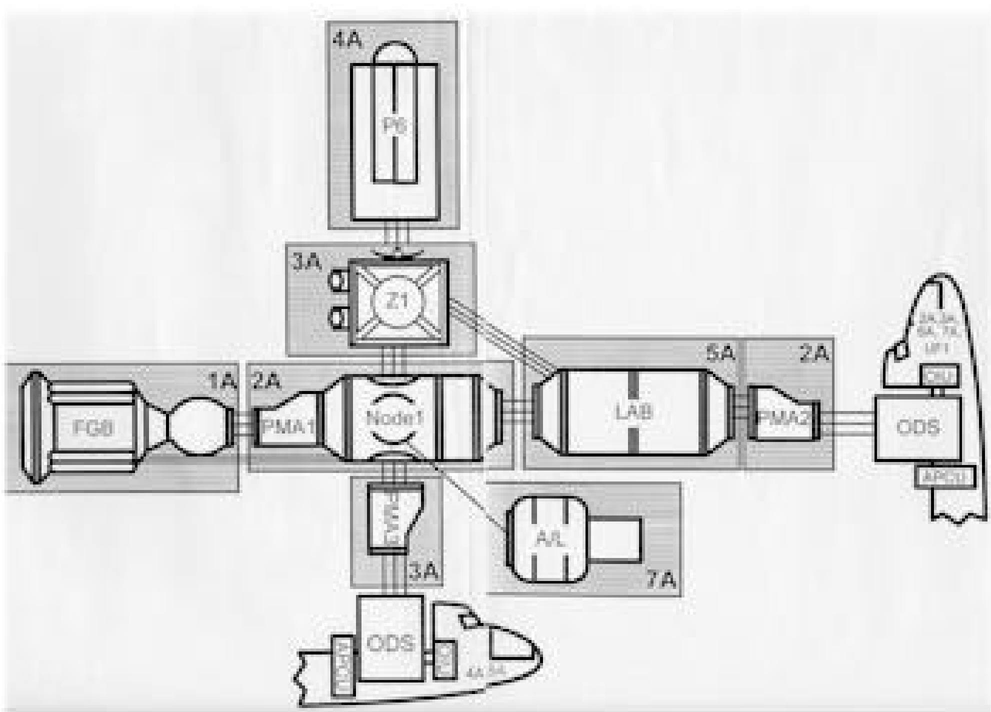
Normally, before NASA launches an Orbitor (Space Shuttle, satellite, etc.) into space, it is completely constructed and fully tested while on the ground. However, due to the large size of the Space Station and the fact that different components will be launched separately, this is not possible. NASA must therefore conduct tests on the compatibility of the different components of the Space Station to ensure that they work properly. These tests are called multi-element, integrated tests or MEIT for short. A MEIT is a test in which several separate Space Station elements are put together as they will be in orbit and the system is tested on the ground before the pieces are launched. Among the various systems that must be tested is Command and Data Handling (C&DH). This system controls all of the hardware and software that operates nearly every electronic device on the Space Station. This system consists of the following equipment:

* Nearly 50 on-board computers
* The software to operate these computers
* Portable laptop computers
* Approximately 100 data buses to connect these computers
* More than 500 other electronic devices

Clearly, to test such a complicated system is an immense task!

Let's take a closer look at the actual architecture of the space station. Consider the diagram given below.

Diagram 1: International Space Station



Basically the Space Station is made up of the following components:

* PMA's (Pressurized Mating Adapters)
  These components are used to attach external items to the main Space Station, such as Space Shuttles that are delivering payloads to the Station.
* Nodes which are connectors between components
* Laboratories
* Portals that could be used as sleeping or eating quarters

A large portion of the Command and Data Handling (C&DH) system is contained in the United States lab (this is indicated as box 5A in the Diagram 1) and consists of the following:

* Three command and control (C&C) computers, one of which will control all other computer operations within the lab and two additional computers to be used as backup systems
* Two computers (abbreviated INT MDM) which can control all of the internal functions of the lab (The internal functions include thermal controls, environmental controls and other controls that make habitation in the lab possible. One of the INT MDM computers will be active while the other is used as a backup.)
* Two computers (abbreviated EXT MDM) which can control all of the external functions of the lab (The external functions include external heating devices and vital connections between the lab and other components of the Station. One of the EXT MDM computers will be active while the other is used as a backup.)
* Three other lab computers which control fire detection, environmental sensors, signal receivers, as well as other devices
* The internal thermal control system (ITCS)
  This system consists of heaters and fluid flow within the lab.
* The electrical power system for the lab
* Data buses that allow all of these components to communicate

The United States lab will be delivered to the Space Station by a Space Shuttle. Before the United States lab can be connected to the Station and occupied, the C&DH system must be initialized. A laptop computer located on a docked Space Shuttle will give the initialization commands. Additionally there will be computers located on the ground at Johnson Space Center in Houston, Texas, that will provide backup for the laptop computer located on the Shuttle. Failure of this initialization process could result in irreparable damage to the United States lab. So, it is critical that the initialization process be fully tested by NASA. Your job in this project is to design and implement a test of this process.

DISCUSSSION QUESTION:
Write a summary of the following:
a) the scientific importance of the International Space Station (ISS),
b) the general layout of the ISS and the C&DH system in the United States lab,
c) the need for testing the C&DH system.

Testing the Command and Data Handling System

To test the C&DH system on the United States Lab, we are going to test 3 subsystems. These are the electrical power system (EPS), the main computer that controls all the other computer operations in the lab (C&C), and the lab's internal computer (INT). You will use your knowledge of logic and truth tables to design the tests. As an example, we will model the test of the electrical power system.

Test 1: Activating the Electrical Power System

When the United States lab is connected to the Space Station, the first system to be activated is the electrical power system (EPS). The astronauts on the Space Shuttle Orbitor will attempt to activate the electrical power system using a portable laptop computer. If they get a response from the EPS, the astronauts will know they have been successful. As a backup system, a computer on the ground at NASA's Johnson Space Center (JSC) in Houston, Texas, will also attempt to activate the EPS. Once a response is received by either of the two computers, the operators will check that the EPS is working at appropriate voltage and current levels. The voltage must exceed 120 volts, and the current must exceed 0.5 amperes. We can model a test of this process using truth tables.

1) Define statements p, q, r, and s as follows.
   p: A response is received by the laptop from the EPS.
   q: A response is received by JSC from the EPS.
   r: Voltage level exceeds 120 volts.
   s: Current level exceeds 0.5 amperes.

2) Use the statements in Step 1 to construct a compound statement that models the test of the EPS. Since either the laptop OR JSC must activate the EPS, the first part of the statement is $p \vee q$. We also need an appropriate voltage level, so the statement becomes $(p \vee q) \wedge r$. Notice that we placed parentheses around the $p \vee q$. This is necessary because AND is evaluated before OR in logical statements. In our test we must first attempt to activate one of the computers before the rest of the test is completed.
   Finally, we need an appropriate current level. The final statement is $(p \vee q) \wedge r \wedge s$.

EXERCISE 1
Construct a truth table for the statement that models the test of the EPS.

3) The test of the EPS will be successful if the final value of the compound statement is true.

EXERCISE 2
In terms of responses, voltage, current readings and the computers giving the commands on the Shuttle Orbitor and at JSC, describe the scenarios under which the test of the electrical power system would fail.

Truth Tables Using Derive for Windows™

Evaluating compound statements can be complicated and time-consuming. The computer program Derive for Windows™ can help evaluate these statements quickly and accurately. We will use the example of the EPS to demonstrate how to use Derive for Windows™. (The Appendix has instructions for constructing truth tables using Microsoft Excel™.)

1) Click on Author, and choose the Expression option.

2) In the dialog box that appears type the following: truth_table(p,q,r,s,($p \lor q) \land r \land s$). You may type the words "or", "and", "not" or you may click on their symbols on the palette. The only way to generate an "exclusive or" statement is to use the expression "xor". Then click OK. The following line should appear on your screen:

   #1: TRUTH_TABLE(p,q,r,s,($p \lor q) \land r \land s$).

3) Click on Simplify, and choose the Basic option.

4) A dialog box will appear. The statement in the box should be the same as the statement above. If this is so, click OK.

5) The truth table should appear.

EXERCISE 3
To practice using Derive™, construct truth tables for the following compound statements:
a) $p \lor q$
b) $p \lor (q \land r)$
c) $(p \land q) \lor (r \land p)$
d) $[(p \land q) \lor (q \land r)] \lor (r \land s)$

Test 2: Activating the Command and Control Computer System

If the test of the EPS is successful, the next system to be activated is the Command and Control (C&C) computer system in the United States lab. The tests on this system will be the largest and most complex of all the C&DH system tests. We will consider only the first two stages of the C&C test, activating the C&C computer system and activating the internal computer.

The main C&C computer system consists of three computers. We will refer to these as #1, #2, and #3. One must be activated as the primary computer, and one must be activated as a backup computer. **All three computers must not be activated at the same time.** The scenario can be outlined as follows:

i) From the laptop on the Space Shuttle Orbitor, either (a) #1 must be activated along with either #2 or #3 as backup, OR (b) if #1 cannot be activated, then #2 must be activated with #3 as backup, BUT (c) #1, #2, and #3 must not all be activated; OR
ii) From the computer at JSC, either (a) #1 must be activated along with either #2 or #3 as backup, OR (b) if #1 cannot be activated, then #2 must be activated with #3 as backup, BUT (c) #1, #2, and #3 must not all be activated; BUT
iii) the C&C computer system must not respond to both the laptop on the shuttle and the computer at JSC.

EXERCISE 4

a) Define all the statements needed to activate the three computers from the laptop on the Shuttle.
b) Define all the statements needed to activate the three computers from the computer at JSC.
c) Write a compound statement for the activation of the C&C computer system from the laptop on the shuttle.
d) Write a compound statement for the activation of the C&C computer system from the computer at JSC.
e) Construct a truth table for the compound statement in (c).
f) Construct a truth table for the compound statement in (d).
g) To simplify the test, give the statement in (c) the name L, and the statement in (d) the name J. Write a compound statement for the activation of the C&C computer system in terms of L and J. Think about how the laptop and the computer at JSC should work together. Do not use all of the statements from (a)-(d). L and J contain them.
h) Construct a truth table for the compound statement in (g).

The test of the C&C main computers will be successful if the final value of the compound statement in (g) is true.

EXERCISE 5

Describe the scenarios under which the test of the C&C main computer system would fail in terms of the computers giving the activation commands (the laptop on the Orbitor and the JSC computer) and the computers to be activated (#1, #2, and #3).

Test 3: Activating the Internal Computer

Once the main C&C computer system is operational, it will be given commands to activate the other computers in the lab. The first computer to be activated is an internal computer. There are two internal computers, which we shall call #1 and #2. Only one of these needs to be activated, and **both of them should not be activated together**. Computer #2 should only be activated if #1 cannot be activated. The scenario can be outlined as follows:

i) From the laptop on the Space Shuttle Orbitor, (a) either #1 or #2 must be activated, BUT (b) both #1 and #2 must not be activated; OR
ii) From the computer at JSC, (a) either #1 or #2 must be activated, BUT (b) both #1 and #2 must not be activated; BUT
iii) the internal computer must not be activated by commands from both the laptop on the shuttle and the computer at JSC.

EXERCISE 6
Using a process similar to the one we used in Exercise 4, design a test of the internal computer system. Be sure to clearly define statements to be used, construct appropriate compound statements, and construct appropriate truth tables.

EXERCISE 7
In terms of Internal Computers #1 and #2 (the computers to be activated) and the computers on the shuttle orbitor and at JSC (the computers giving the commands), describe the scenarios under which the test of the internal computer system would fail.

Testing: Summary and Report

EXERCISE 8
Suppose that you work at NASA's Kennedy Space Center, and that you are in charge of testing the C&DH systems. Write a memo to your supervisor discussing the process used to test the C&DH systems and describing the situations in which the test would fail. Remember that your supervisor is busy and may not be trained in computer software testing. This means you will need to explain yourself clearly without making your memo too long.

Appendix

Directions For Using EXCEL™ To Generate Truth Tables

Microsoft EXCEL™ can be used to generate truth tables using the following steps.

1) Open a new workbook (or worksheet in EXCEL™).

2) Label cell A1 as P, cell B1 as Q, cell C1 as R and cell D1 as S. You should label cell E1 as (P or Q) and R and S. You might want to format column 5 to fit this label. You can do this by highlighting cell E1, clicking on Format, selecting column and selecting AutoFit Selection.

3) Type the word TRUE in cell A2. It is important that this be capitalized.

4) Drag and drop, cell A2 so that TRUE is in cells A2 to A9.

5) Type the word FALSE in cell A10. It is important that this be capitalized

6) Drag and drop, cell A10 so that FALSE is in cells A10 to A17

At this point your sheet should look as follows:

P	Q	R	S	(P or Q) and R and S
TRUE				
TRUE				
TRUE				
TRUE				
TRUE				
TRUE				
TRUE				
TRUE				
FALSE				
FALSE				
FALSE				
FALSE				
FALSE				
FALSE				
FALSE				
FALSE				

7) Now you will fill in columns B, C, and D with TRUE and FALSE. When you are finished your sheet should look as follows:

P	Q	R	S	(P or Q) and R and S
TRUE	TRUE	TRUE	TRUE	
TRUE	TRUE	TRUE	FALSE	
TRUE	TRUE	FALSE	TRUE	
TRUE	TRUE	FALSE	FALSE	
TRUE	FALSE	TRUE	TRUE	
TRUE	FALSE	TRUE	FALSE	
TRUE	FALSE	FALSE	TRUE	
TRUE	FALSE	FALSE	FALSE	
FALSE	TRUE	TRUE	TRUE	
FALSE	TRUE	TRUE	FALSE	
FALSE	TRUE	FALSE	TRUE	
FALSE	TRUE	FALSE	FALSE	
FALSE	FALSE	TRUE	TRUE	
FALSE	FALSE	TRUE	FALSE	
FALSE	FALSE	FALSE	TRUE	
FALSE	FALSE	FALSE	FALSE	

8) Highlight cell E2, click on Insert, and select Function. The function wizard box step 1 box will appear. Under Function Category select the item called Logical. Under Function Name select AND, then click on Next. The Function Wizard Step 2 box will appear. In the logical1 box type: OR(A2,B2), in the logical2 box type: C2 and in the logical3 box type: D2. Click on Finish to complete the formula.

9) Drag and drop cell E2 so cells E2 to E17 have truth values. Your final sheet should look as follows:

P	Q	R	S	(P or Q) and R and S
TRUE	TRUE	TRUE	TRUE	TRUE
TRUE	TRUE	TRUE	FALSE	FALSE
TRUE	TRUE	FALSE	TRUE	FALSE
TRUE	TRUE	FALSE	FALSE	FALSE
TRUE	FALSE	TRUE	TRUE	TRUE
TRUE	FALSE	TRUE	FALSE	FALSE
TRUE	FALSE	FALSE	TRUE	FALSE
TRUE	FALSE	FALSE	FALSE	FALSE
FALSE	TRUE	TRUE	TRUE	TRUE
FALSE	TRUE	TRUE	FALSE	FALSE
FALSE	TRUE	FALSE	TRUE	FALSE
FALSE	TRUE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	TRUE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE
FALSE	FALSE	FALSE	TRUE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE

This is the final truth table. You should note that the other logical functions OR and NOT are available on the Insert Function menu. The function XOR is not built into EXCEL™. The statement p XOR q is logically equivalent to $(p \vee q) \wedge \sim(p \wedge q)$. So p XOR q can be modeled in EXCEL™ using the following function combination:
AND(OR(p,q),NOT(OR(p,q))

EXERCISE 3
To practice using EXCEL™, construct the following truth tables:
a) $p \vee q$
b) $p \vee (q \wedge r)$
c) $(p \wedge q) \vee (r \wedge p)$
d) $[(p \wedge q) \vee (q \wedge r)] \vee (r \wedge s)$