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Pluto Express Preproject Curriculum Guide

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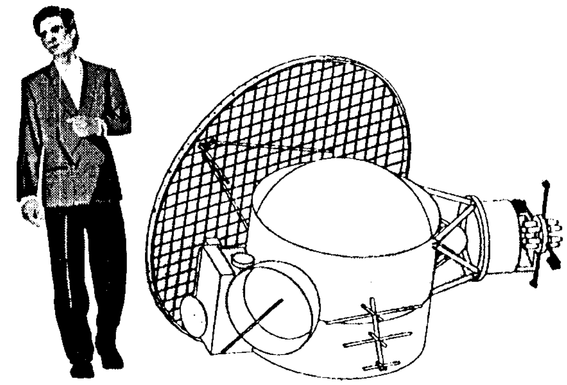
SMALL. SPACECRAFT TECHNOLOGY

by Richard Shope

Aerospace designers are aggressively pursuing new ideas in advanced technology for smaller spacecraft, NASA's "faster, better, cheaper" philosophy is the driving force to accomplish higher level scientific exploration more efficiently, The Pluto Express Prepr'eject at the Jet l'repulsion Laboratory is at the cutting edge of these emerging technologies--- producing not just spacecraft, but *sciencecraft.* Instead of the traditional approach of assembling a structure and fitting instruments around its limitations, the overall design is shaped by the science objectives at the outset. Scientists, engineers, and designers work together to create sophisticated robotics-- essentially, *extensions of the human senses.*

More memory and higher performance is packed into computer hardware that takes up a fraction of the space of earlier generation spacecraft. Attitude controls, propulsion systems, cameras-- nearly every component has been miniaturized with a gain in performance. Total integration of spacecraft components reduces the need for complex cabling, which in turn significantly reduces mass. Research into the behavior of construction materials continues to advance as components must withstand launch vibrations, solar radiation, near vacuum conditions, weightlessness, and tremendous extremes of temperature change.

The Pluto Express spacecraft is "faster, better, cheaper"— and smaller: 76 **kg (dry mass w/probe); 105 kg (wet mass w/propellant). Even lighter designs are being considered.**



☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂
Wet mass is not what happens if you
leave the spacecraft out in the rain!
☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂ ☂

These advances represent true leaps in technological development. This affords a new way to explore the planets. Miniaturization reduces the mass of the *sciencecraft*— which means a scaling down of costs and substantial savings in energy consumption at launch.

Educational Objectives

At-A-Glance

1 To INVOLVE students kinesthetically to learn about small spacecraft technology,

2. To IDENTIFY the components of a small spacecraft.

3. To STATE the advantages of small spacecraft tethnology.

4. To DEFINE: *miniaturized, performance, quality assurance, redundancy, small spacecraft.*

5. To DESCRIBE the process of selecting components for a small spacecraft.

Key Questions For Discussion

- Why is miniaturization an importan technological development?
- What does the motto "faster, better cheaper" mean to the space program?
- What is the difference between *mass* and *weight?*
- What factors must a mission team consider as it selects components for the spacecraft?
- How do you test a component for flight readiness?

insi

A Metric Reminder!

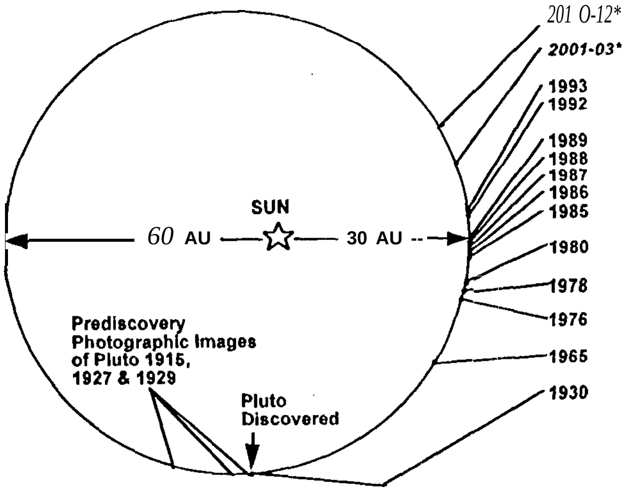
1 kilogram = 2.2 pounds
1 pound = 0.45 kilograms

A Sciencecraft Approach to Aerospace Design

A *sciencecraft* approach means we must consider first what we want to learn about the place we want to explore. While thi **may seem** *obvious—OF COURSE* we want to outfit the spacecraft with the right instruments for the exploration job w **have in mind!** But we have to remember, space exploration began in earnest less than FORTY YEARS AGO! Only as w have gathered collective experience do we understand the range of options we really have. Every space flight has contribute our knowledge. Early space flight design was limited by the structural considerations. We knew what was needed to put a satellit to space, and we hung the instruments wherever they would fit--- much as we might decorate a Christmas tree with ornaments.

Now, with a better perspective, we can plan our design around the questions we want to ask. After all, life begins at fort ow a spacecraft can become smarter; now it can become a *sciencecraft.*

So what do we want to know' about PLUTO & CHARON? Hmmmm! What do we already know?



⇒ 2010-12: *Data Retrieval, First Images Returned from the Pluto System*
⇒ **2001-03:** *Pluto Mission Proposed Launch*
**Different Dates for launch and retrieval are under discussion*
⇒ ***1993:*** Pluto /Charon barycenter located and mass determined using the Hubble Space Telescope
⇒ 1992: Discovery of nitrogen (N_2) and carbon monoxide (CO) ice on Pluto; discover) of significantly different densities
⇒ 1989: Suggestion of thermal structure *in Pluto's* atmosphere
⇒ 1988: Discovery that Pluto's orbit is chaotic; stellar occultation reveals Pluto's atmosphere; eclipse evidence for polar caps
⇒ 1987: Discovery of water (H_2O) ice on Charon
⇒ 1986: Determination of separate albedos and colors for Pluto and Charon; First reliable radii for Pluto and Charon
⇒ 19S5: Onset of Pluto-Charon mutual events
⇒ 1980: Stellar occultation reveals Charon radius ***mar 600*** km
⇒ ***1978:*** Discovery of Charon, mass of Pluto + Charon determined
⇒ 1976: Discovery of methane (CH_4) ice on Pluto
⇒ 1965:3:2 Orbit resonance with Neptune discovered
⇒ 1930: Discovery of Pluto

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Background Discussion

Spacecraft Teams need to establish a clear purpose for each mission- and this determines what capacities need to be built into the spacecraft. The Core Science Objectives are the central criteria which determine what instruments will be placed onto the spacecraft. They are the questions scientists wish to ask! Questions scientists ask are based on uriosity, on what we have learned by exploring other planets, and on the possibilities opened up y the advance of technology. We can ask more detailed questions as we design and build smaller, nore efficient instruments to answer them.

What does the surface of Pluto look like? And its moon Charon ? And what are they nade of? The Pluto spacecraft needs a variety of science instruments to study Pluto & Charon. The data needs to be recorded and radioed back. So the spacecraft needs a radio transmitter and n antenna that is pointing back to Earth.

What is the atmosphere like on Pluto? Pluto began to move away from the Sun after its closest approach in 1989. In 1999, Pluto crosses the orbital path of Neptune and becomes once again the outermost planet in the Solar System. But for now, it has a gaseous atmosphere, its cold vapors purling in the deep freeze, as the sunlight is just barely strong enough to stir it from its surface. We can place instruments aboard that can measure changes in the light passing through the atmosphere and by sending a probe directly to the surface with instruments to measure atmospheric density and chemical composition.

If the Pluto Express doesn't leave soon after the turn of the century, the atmosphere o Pluto may freeze back to the surface before we can get there, and humanity will have to wai another two-and-a-half centuries before we can answer these burning questions!

Pluto Express Core Science Objectives

To Pluto or Not to Pluto: These Are the Questions!

Early in the history of space exploration, our questions were very basic: Where are we going? *Planet hopping!* What's the environment like there? *Hot & Cold, subject to Solar radiation!* What does the spacecraft have to look like to get there? *Hardy enough to handle launch vibrations, with an antenna to beam back to Earth!* Then, within the limitations of the spacecraft we would hang on as many science instruments as we could--- and then try as best we could to coordinate the effort.

In these past forty years, we have flown hundreds omissions to space. We have evolved many design options to serve many purposes. Technology has advanced on many fronts: computers, optics, propulsion. We have a better understanding of how many materials behave in space. We have a better idea about what can go wrong and more importantly, *what can go right!*

Now, building upon this body of experience, a new way to explore the planets has opened up. We can start with the science objectives and create an integrated design around the questions. *What do we want to find out? What do we want to learn?*

The NASA Outer Planets Science Working Group has agreed upon a set of Core Science Objectives, as follows:

What We Want to Know About Pluto/Charon

Category 1a: ToP Priority
Characterize Global Geology & Morphology
Surface Composition Mapping
Characterization of Neutral Atmosphere Structure and Composition

Category Ib: Second Level Priority
Surface and Atmosphere Time Variability
Stereo Imaging
High Resolution Terminator Mapping
Selected High Resolution Surface Composition Mapping
Characterization of Pluto's Ionosphere and Solar Wind Interaction
Search for Neutral Species Including: H, H_2, HCN, C_xH_y, and other Hydrocarbons and Nitriles in Pluto's Upper Atmosphere.
Obtain Isotope Discrimination Where Possible
Search for Charon's Atmosphere
Determination of Bolometric Bond Albedos
Surface Temperature Mapping

Category Ic: Third Level Priority
Characterization of the Energetic Particle Environment
Refinement of Bulk Parameters (Radii, Masses, Densities)
Magnetic Field Search
Additional Satellite and Ring Search

Source: NASA Outer Planets Science Working Group

An Extension Of The Human SENSES!

What does Pluto/Charon LOOK LIKE?
What is the layout of the terrain?
Can we draw a map of Pluto/Charon?
Are there volcanoes? craters? mountains?
What color is everything?
What does the sky look like from Pluto/Charon?

What does Pluto/Charon FEEL LIKE?
What kind of rock formations are on the surface?
What kind of ice formations are on the surface?
Is the ground hard, rocky, icy?
What is the temperature in the day& night?
Can we detect its magnetic field?

What does Pluto/Charon SMELL LIKE?
What kind of air does Pluto/Charon have?
What kind of gases evaporate from the ices?

What does Pluto/Charon TASTE LIKE?
What is the chemistry of Pluto/Charon?
What are the ices of Pluto/Charon made of?

What does Pluto/Charon SOUND LIKE?
Can you hear the wind blow? the solar wind?
Can we detect the vibration of particles?

Project Scientists, Engineers, and Designers and others work together to produce a sciencecraft that will explore as many of these questions as possible. Precise instruments will be discovered or invented do the job. This is called the *payload.* The science instruments must be arranged in such a way that they can work together without conflict. A precise sequence of events must be worked out so that each instrument does its job at the right time and place. Materials must withstand the extreme conditions of launch vibrations and the cruising environment. A communication system must be designed to tell the spacecraft what to do from Earth and to send the information back to Earth. A power source must be designed to energize the spacecraft and operate all the instruments.

Every part of the spacecraft must be tested for *mission assurance—* to make sure that every component will function properly. Duplicate systems must be included, just in case. This back-up plan is referred to as *redundancy.*

Now, we're ready to start experimenting with sciencecraft designs!

Exercise 1: Build Your Own Spacecraft

Build A Living Spacecraft— *using students as components!*

Form Small Groups of Builders: Build the Spacecraft using members of each group as components.
Groups of three to five work out best. Use your bodies& use props from materials at hand if you wish!

Using the information in this guide, other sources, and your own imagination, create ways of BEING:

♦ Spacecraft Bus, the main structure that holds everything, together;

♦ Antenna and Telecommunications System, staying in touch with Earth;

♦ Power Source, to energize the spacecraft to keep on going;

♦ Star Tracker, Sun Sensor, & Attitude Thrusters, to navigate through space;

♦ Science instruments, cameras, spectrometers, anemometers, magnetometers, devices to record surface images and to determine weather patterns.

Once the Living Spacecraft is Constructed, conduct a Simulated Flight Test:
Guide the Spacecraft through manuevers using words as if they
were the bits of encoded messages send to the on-board computer.

Be as precise as possible!

Be aware of the Sequencing of Commands!

Direct the spacecraft to point the camera where you want it !

PLUTO SPACECRAFT COMPONENTS (1995)

Component	Estimated Mass	
Structure (Bus) & Thermal Control	13 kg	29 lb
Telecommunication: Radio & Antenna	15 kg	33 lb
Power: Radioisotope Power Source (RPS)	6 kg	13 lb
Propulsion (Including Attitude Thrusters)	10 kg	22 lb
Science: Visible, Infrared & Ultra Violet; & Other Instruments	7 kg	15 lb
Computer & Electronics: Guidance and Mission Sequencing	15 kg	33 lb
Contingency (15%)	***10 kg***	***22 lb***
Total Dry Mass	**76 kg**	**167 lb**
Russian Space Probe to be Dropped to Pluto/Charon	15 kg	33 lb
Propellant (310 m/s delta-V; direct trajectory)	14kg	30 lb
Total Wet Mass	**105 kg**	**230 lb**

A small spacecraft can be defined as one whose mass is under 600 kg (about 1325 lb). The current spacecraft design— still evolving as new components are developed— has a *wet mass of* 105 kg (about 230 lb) .

Dry mass refers to the mass of the spacecraft itself; *wet* mass includes the propellant used to move the spacecraft, in this case, the propellant used to operate the attitude control thrusters.

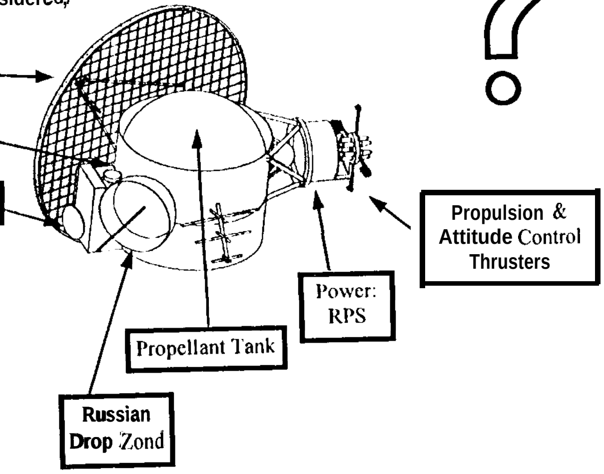
A SPACECRAFT IS BORN

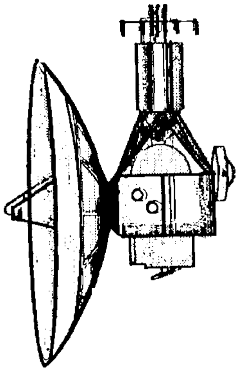
A spacecraft needs a basic structure-- a backbone--to which the components are attached. This is called the *bus*. Selection of the components depend on the purpose of the mission. The Pluto Express Spacecraft design is still evolving. Its final design will reflect a combination of science, engineering, technology, artistry, imagination, and budgetary limitations. These pictures will give you an idea of the benchmark design options as they have evolved since 1991.

Final Design ?

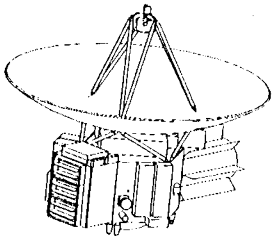
1995 Design

(One of several options being considered)

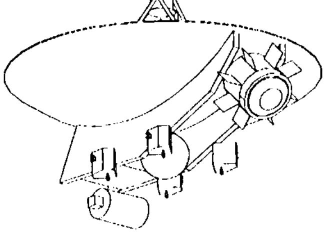




1994 Design



1992 Design



1991 Design

Exercise 2: Shake, Rattle, & Roll

COMMENTARY

Before launching anything into space, we have to make sure it will work! If you get a flat on the way to the lake, you can just pull off the road and change the tire. The risk factor is very low. If you're in orbit around Earth, you might be able to send up a crew of Space Shuttle astronauts to fix it– like we did with the Hubble telescope. Higher risk, but's it is feasible. But when you're way out there in the outer reaches of the Solar System, *who you gonna call?*

Today, we have two main approaches to this sort of high risk:

1) Mission Assurance: test it out in as many creative ways that will simulate the actual conditions that are likely to be encountered.

2) *Redundancy:* Be redundant. Again, I say, be redundant. Put two components aboard; if one fails, the **other acts as a back-up.**

MISSION ASSURANCE

ACTIVITY: Let each group subject its spacecraft to quality assurance tests:
Put on some wild music and *shake, rattle, and roll!*

Each component must be tested for *mission assurance. The* component must be able to withstand the conditions of space and must endure the long trip— and be ready to function properly after seven to ten years, after the long ride! At the Jet Propulsion Laboratory, there is a special building where spacecraft components are tested for flight readiness. Essentially, assembled components are *shaken, rattled, and rolled* to simulate the conditions experienced during the extreme stress of the launch and the severe environmental conditions during the flight. Components are also subjected to extremes of temperature, and other various tests. Our ability to test is limited by current technology— and we have virtually no method at all to test for the behavior of components in conditions of weightlessness. There is no such thing as an anti-gravity room on Earth. The closest we can come is to fly a plane in a parabolic pattern to achieve a free fall—virtual weightlessness— for about 30 seconds. Nevertheless, we have learned a great deal from the actual experience of sending spacecraft up and having things *work!*

BE BE BE REDUNDANT REDUNDANT!

ACTIVITY: Let each group consider which components ought to be redundant.
Modify the design to reflect those decisions.

Redundancy planning refers to the inclusion of back-up components---just in case something breaks down. Even in the best of worlds, things can go wrong. For instance, another antenna on *Galileo* salvaged the project when the main antenna failed. In general, the idea is to design the spacecraft with back-up components for key systems: spacecraft designers need to make tough decisions— we do not have the luxury to double every key component, due to mass considerations and expense. Much of the decision-making has to do with determining reliability from quality assurance tests and actual flight experience and then weighing the relative risks involved.

KEY QUESTIONS FOR DISCUSSION

- ♦ What is the G-force exerted on spacecraft during launch?
- ♦ What other kinds of tests might be needed to assure that a component will work?
- ♦ What other activities in your life might benefit from thinking about *quality assurance* and *redundancy* ?
- ♦ How do you analyze *risk* in other activities in your life?

Exercise 3: SPACECRAFT CONTROL

Cruising With an Attitude

KEY CONCEPT How Spacecraft Navigate During Cruise Time

Once the spacecraft has reached its *parking orbit*, the final launch sequences loft it into its direct trajectory toward Pluto. The parking orbit must be in the same plane as its cruising trajectory to be energy-effective. During the long eight-year cruise, adjustments may need to be made to assure that the spacecraft is on course. This is accomplished through a set of tiny thrusters called *attitude controls*. Attitude refers to the position of the spacecraft. In space, a small *poof!* of propellant can alter the trajectory precisely.

ACTIVITY

Small Group Simulation

Form groups of three:
Let one person be the spacecraft, let a second be the attitude thrusters, and let the third be ground control.

Remember the principle: ***for every action, there is an equal and opposite reaction.***

With specific Action/Reaction behaviors in mind: let the fingers of the second person exert the force of the attiutde thrusters against the shoulders of the spacecraft person to adjust position and direction of motion.
Guide the spacecraft through space by having ground control use words to engage thrusters— be specific!
Devise ways to communicate amount of thrust.
Observe and record experimental test runs.

Variation

Let one person be the spacecraft. Rig up several conical, color-coded attitude control thrusters, and attach to spacecraft.

Variation

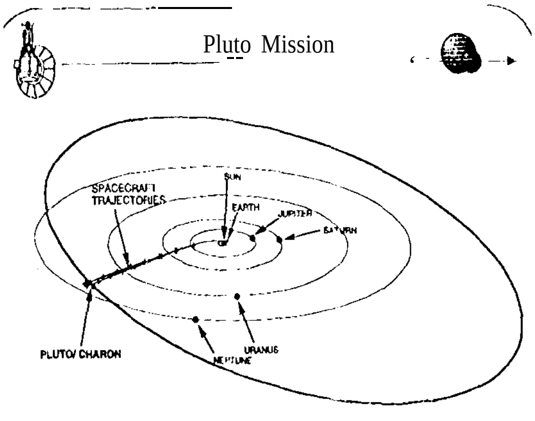
Guide the previously constructed **group spacecraft through space by** designing *your own* attitude control **system.**

EDUCATIONAL OBJECTIVES

AT-A-GLANCE

1. To IDENTIFY the instruments involved in attitude control.
2. To STATE the basic principles of Action and Reaction.
3. To DEFINE: *attitude control.*
4. To DESCRIBE the whole process of navigating spacecraft.

Pluto Mission



VARIATIONS

Attitude in terms of *Emotions*

Steering ourselves emotionally through Earth Space

How many different ways can you use the word attitude?

Exercise 4: Pluto Spacecraft, Call Home!

COMMENTARY

The purpose of the spacecraft is to record data that can be sent back to Earth. An effective system of communicant ion needs to be designed for this to be accomplished, thus the importance of antenna quality, time scheduled on the Deep Space Network, and the design of computer technology used to pass messages to and from the spacecraft.

What's involved in communicating with SPACECRAFT?

- Designing an antenna and keeping it pointed at Earth;
- Designing software that allows Earth-Spacecraft-Earth communication;
- Anticipating communication needs and designing response capabilities;
- Traffic Jams on the information Superhighway, the Deep Space Network;
- Costs involved in monitoring data, both money and personnel.

Key Concept: Communicating with a Spacecraft

1 To IDENTIF% instruments involved in communication with spacecraft.

2 To STATE the basic principles of radio communication with spacecraft.

3 To DEFINE: *radio* ***waves, DSN, upload download hardware, software.***

4 To DESCRIBE the whole process of communicating with spacecraft.

JPL Home Page: http: //www.jpl.nasa.gov

Sourcebook: ***Technology for Small Spacecraft*** **a publication of the Aeronautics & Space Engineering Board National Research Council, Available for sale from:**

National Academy Press
2101 Constitution Ave. N.W. Box 285
Washington, D.C. 20055

ACTIVITY

Form Spacecraft Teams: Devise an effective communications systems to guide a human spacecraft through the Solar System (your classroom or playground). Plan out the Sequence of steps that need to be communicated !

Telecommunications!

Pluto Spacecraft, Phone Home! The basic infrastructure of the Deep Space Network and NASA-JPL ground operations needs to stay in place even many years to continue monitoring the Pluto spacecraft, Once it is out there 3 billion miles away, radio communication takes about four hours--each *way!*

Current configurations take advantage of new antenna design possibilities to communicate on the Ka-Band frequency. Advanced planning and insightful computer programming guiding the spacecraft and directing its sequence of moves are crucial to maintaining contact in order to retrieve the desired information.

◆ How do we know if the spacecraft UNDERSTANDS our commands?

◆ What kind of interference to telecommincation occurs in space?

SOURCES & BIBLIOGRAPHY

Hartmann, William K. (1992). The Cosmic Voyage. Belmont, CA: Wadsworth Publishing Co.

Isakowitz, StevenJ.(1991). International Reference Guide to Space Launch Systems. Washington, D. C.: American Institute of Aeronautics and Astronautics

Shelton, William (1968). *Soviet Space Exploration: The First Decade. New* York: Washington Square Press.

Riabchikov,Evgeny(1971). *Russians in Space.* Garden City, New York: Doubleday& Company.

Zeilik, Michael (1976). *Astronomy: The Evolving Universe. New* York: Harper& Row.