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AEROASSIST TECHNOLOGY PLANNING FOR EXPLORATION

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Now that the International Space Station is undergoing assembly, NASA is strategizing about the next logical exploration strategy for robotic missions and the next destination for humans. NASA's current efforts are in developing technologies that will both aid the robotic exploration strategy and make human flight to other celestial bodies both safe and affordable. One of these enabling technologies for future robotic and human exploration missions is aeroassist. This paper will (1) define aeroassist, (2) explain the benefits and uses of aeroassist, and (3) describe a method, currently used by the NASA Aeroassist Working Group, by which widely geographically distributed teams can assemble, present, use, and archive technology information.

INTRODUCTION

As NASA continues to send robotic missions out into the Solar System, and begins plans for humans to follow, the challenge is to find mission approaches that decrease cost and risk. Concepts for human missions to Mars and robotic missions to other destinations have been under development for some time. These point designs help to identify areas where improvements in our current space flight technologies are required to make these missions viable and affordable. Next, plans or roadmaps are made which show a logical progression of research, ground tests, and flight demonstrations, to bring the needed technologies to the appropriate level of readiness for inclusion on these missions. Aeroassist is a key technology that enables or enhances planetary exploration for both advanced robotic missions and human missions.

Aeroassist Definitions

Aeroassist refers to the use of an atmosphere to accomplish a transportation system function. The term includes aerobraking, aerocapture, aeroentry, precision landing, hazard detection and avoidance, and aerogravity assist. Some examples will help define the aeroassist elements listed above.

The Mars Global Surveyor was captured into a highly elliptical orbit about Mars using a propulsion system. Subsequently, in order to reach its desired circular-mapping orbit, it spent several months "aerobraking"--dipping into the uppermost portions of the Martian atmosphere to adjust its altitude. Aerobraking maneuvers were used over a total of nine months to gradually reduce its initial apoapsis from 56,000 km to 400 km. This procedure was used to reduce the fuel requirement by an equivalent of 1200 m/s delta-V.

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"Aerocapture" is different than aerobraking in that it is a single pass through an atmosphere that takes enough energy from the trajectory to change it from hyperbolic to elliptical with respect to the planet. Thus aerocapture replaces the initial propulsive capture maneuver and can reduce or eliminate the need for aerobraking. This can save a significant amount of propellant, and is enabling for most human missions to Mars. As a note, if a highly efficient propulsion system, such as nuclear, is used, there may be no advantage to aerocapture. Aerocapture is planned to be demonstrated for the first time on the Mars Sample Return Orbiter, built by the French space agency CNES, currently scheduled to launch in 2005.[1]

"Aeroentry" is more common than either aerobraking or aerocapture. It is required whenever a vehicle descends to the surface of a body that has an atmosphere. The Space Shuttle performs aeroentry every time it returns from orbit. The Viking landers, Mars Pathfinder, and the Mars Polar Lander all performed aeroentries, but Mars Surveyor '01 will be the first lander on another planet to use a guidance algorithm to actively control the entry.[2] "Precision Landing" is the result of a guided aeroentry. Entry control and targeting capability is necessary for reducing the size of the landing footprint (area of possible landing locations). The use of "Precision Landing" will allow the Mars Surveyor '01 lander to land within a 10-km circle, as compared to the 300-km by 60-km ellipse of Mars Pathfinder. At the end of the entry, "Hazard Detection and Avoidance" (HDA) may be used to detect rocks, craters, slopes, or man-made objects on the surface of a planet, then to divert the vehicle's trajectory to a safe location.

A vehicle performs "Aerogravity Assist" by using a combination of atmosphere and propulsion to modify its hyperbolic orbit; essentially an aerodynamically-assisted swingby. An aerodynamic vehicle with a high lift-to-drag ratio is used; it creates downward lift to "hold" itself in the atmosphere, allowing it to bend through a large angle. This use of aerodynamics and gravity allows for a larger bend angle than would be possible through the use of gravity alone. This synergism allows the smaller planets to be as effective as the larger planets in providing shorten trip times. Low drag is required to minimize the planet relative velocity loss during the atmospheric passage that would have to be added propulsively.

Contributing Disciplines

Besides pertaining to several mission phases, aeroassist systems require the synthesis of many different disciplines. These include guidance, navigation, and control, aerodynamics and aerothermodynamics, structures, thermal protection systems, and vehicle design. All of these can contribute to improvements in vehicle performance, overall mass, and mission cost.

Aeroassist Applications and Benefits

Exploration missions planning to use aeroassist can be divided into 4 categories, which drive the technology development schedule. These four categories are illustrated by the following missions. These are, in chronological order: Mars robotic missions (the Mars Surveyor and Mars Sample Return Programs, through 2005), Mars Robotic Outpost missions (planned to be performed after Mars Sample Return, 2007-2009), Solar System Exploration missions (to destinations other than Mars, starting in 2008-2009), and Human Mars missions (sometime after 2009). The benefits of aeroassist to each of these mission categories are explained below.

The near-term Mars robotic missions are already largely defined in terms of vehicle shape and performance requirements. The lander heatshields are derivatives of the Viking aeroshell shape. Aeroassist technology can be used to reduce the landing footprint from the order of three hundred kilometers for non-guided entries to less than ten kilometers using guidance. The use of an active guidance is planned for first use with the Mars Surveyor Program 2001 Lander, and if successful, will likely be used by the Mars Sample Return 2003 and 2005 Landers. These more precise landings allow scientists to place instruments closer to features of interest, and can shorten the distances rovers traverse, saving valuable time. Shrinking the landing footprints also reduces landing risk; it is easier to find a 10-km area without craters or large rocks than it is to find a 300-km-long area with the same characteristics.

Also in the category of near-term Mars robotic missions is the Mars Sample Return 2005 orbiter. Built by the French space agency CNES, it will be the first vehicle to perform an aerocapture. The benefit is the mass savings compared to a propulsive capture. The heatshield is less massive than the fuel required to achieve an elliptical orbit, allowing both the lander and orbiter for the 2005 opportunity to be launched on a single Ariane V launch vehicle. In addition, aerocapture eliminates months of operationally intensive aerobraking into the final orbit. The orbiter's heatshield shape is that of NASA's Aeroassist Flight Experiment of the 1980's (program cancelled before flight). This used a raked cone aeroshell with an L/D of about 0.25. NASA is working with CNES to verify the aerodynamic performance of this shape at Mars and to define the guidance algorithm that will be used during aerocapture. If the aerocapture is successful, it could pave the way for other orbiters to use this technique.

There are several proposed scenarios for the next set of missions known as "Mars Robotic Outpost" missions. In one scenario, these missions will incrementally establish a long-term robotic presence on the planet followed by the delivery of larger, more massive payloads for use by future human explorers. Aeroassist technologies would be used to place these assets on the Martian surface. Precision landing and hazard detection and avoidance will be capabilities necessary to safely land several sets of resources in the same vicinity. There will also be several effects from delivering larger, more massive payloads. For orbiting assets, aerocapture will become more advantageous from a mass perspective, as described earlier. For both aerocapturing orbiters and landers, aeroshells may have to change from the Viking shape to accommodate increased volumes. This also depends on the available diameter of the launch vehicle shroud, and the mission strategy. If new shapes are flown, they may have increased lift-to-drag ratios, allowing more control during aeroassist maneuvers.

Aeroassist is also useful at bodies other than Mars. In the Solar System Exploration program, aerocapture is enabling for many scientific destinations to remain within the launch constraints of today's launch vehicles. These destinations include Neptune, Saturn, and Titan. Aerocapture is enabling for these missions because the atmospheric encounter speeds are significantly higher than those at Mars. These higher encounter speeds would require an excessive fuel allotment to propulsively capture.

Finally, the human missions to Mars will benefit from almost every aspect of aeroassist. The payloads are so large and massive that aerocapture will be essential for minimizing launch costs and Earth-to-orbit logistics. Also, capturing into Mars orbit before committing the crew to a landing will allow dust storm avoidance, control of the lighting conditions at the landing site, and an accurate navigation state before the next mission phase. Guided aerocapture and aeroentry using a vehicle with an increased L/D from today's missions will provide robust corridor widths and capability to overcome atmospheric dispersions. These higher L/D vehicles also enable G-limited trajectories, which are necessary for crew survival. These mission modes and capabilities all contribute to minimizing risk. Precision landing and hazard detection and avoidance are necessary for safe landing near predeployed resources. A small landing footprint is essential in this case, so that the deconditioned crew does not have far to walk to the surface assets.

State of the Technology

Table 1 compares the aeroassist experience that will exist at Mars through the planned 2005 missions with that required for future human missions. In general, table 1 shows that human missions will be of a much larger scale than any previous Mars payloads, and will require guided, G-limited aerocaptures and entries, precision landings to within 1 km, and hazard detection and avoidance.

Table 1
COMPARISON OF AEROASSIST EXPERIENCE AND NEEDS

	(Projected) Mars Aeroassist Experience through 2005 Mission	Human Mars Mission Aeroassist Requirements
Aerocapture	Load limit imposed by vehicle design. Generally large compared to human missions	Load limit < 5 Earth G's imposed by crew tolerance
Aeroentry	Load limit imposed by vehicle design. Generally large compared to human missions	Load limit < 5 Earth G's imposed by crew tolerance
Precision Landing	Footprints ≈10 km	Footprints ≈1 km
Hazard Detection and Avoidance	No use currently planned	Required
Vehicle Mass	< 5 mt	60-100 mt

The requirements for the Mars Outpost and Solar System Exploration missions, which would take place in the 2008-2011 timeframe (and beyond) are not included here.

The NASA Aeroassist Working Group

To plan the work necessary to move from the current aeroassist capabilities to those needed in the future, a NASA Aeroassist Working Group (AWG) was formed in March of 1999, led by Langley Research Center and currently staffed with representatives from five of the NASA centers. The centers include Langley Research Center (LaRC), Jet Propulsion Laboratory (JPL), Johnson Space Center(JSC), Ames Research Center(ARC), and the Marshall Space Flight Center(MSFC). The team reports to an integrated Human/Robotic Exploration Team (HRET), led jointly by JPL and JSC. The AWG is under the purview of the Space Transportation Office at MSFC. The AWG is specifically responsible for:

- Formulating aeroassist technology development strategies
- Defining goals for aeroassist technology demonstrations (ground development, tests and missions)
- Supporting human mission architecture development
- Supporting robotic mission architecture development
- Defining vehicle designs and requirements which pertain to or are affected by aeroassist
- Preparing proposals to accomplish aeroassist technology priorities within the available funding levels
- Reviewing analyses, plans, and testing of aeroassist systems, to ensure they are coordinated, cost effective, and technically sound.

The AWG is divided into five subteams representing the disciplines that are involved in aeroassist: Aerodynamics and Aerothermodynamics; Guidance, Navigation and Control; Structures; Thermal Protection Systems; and Vehicle Design. Each discipline requires a unique development effort with a corresponding schedule and funding profile before it can contribute to an aeroassist system. However, the efforts of all disciplines must be coordinated into a technology plan, commonly called a "technology roadmap."

The aeroassist technology milestones are driven by the missions and timelines described above. Each improvement must be available in time to support the intended mission. For missions to Mars, opportunities occur every 26 months. For missions to the outer planets, opportunities are less frequent, with the first ones occurring in the 2008 timeframe.

METHOD

The challenge for the AWG is to efficiently identify, organize, and communicate task content and budget requirements. Many technology development efforts have a roadmap, most often a graphical representation of key development activities positioned on a timeline. The AWG has employed a hierarchical method for organizing and displaying their aeroassist information. It consists of a graphical roadmap, hyperlinked to individual task descriptions and schedules, which are in turn hyperlinked to background information, budgets and workforce, and other data as necessary. Individual task leaders can plan their work, formulate their budgets, and link test data, photographs, or presentations to the top-level roadmap. The method is straightforward, expandable, and can be applied to almost any situation. Standard Microsoft Office™ products are used, so team members do not need special software or training. Files are shared with team members from a password-protected server, through a Web browser interface.

The following section will explain, step-by-step, how the aeroassist roadmap is constructed. This method is applicable to any similar task of organizing and sharing information. The actual aeroassist roadmap will not be shown, since it is a work in progress and its content is continually being updated.

Top Level Roadmap Slide

The central roadmap file is a Microsoft PowerPoint™ presentation that takes advantage of the built-in Hyperlink feature. An example top-level, graphical roadmap is shown in figure 1. It consists of boxes and text, all generated within the application. Along the bottom is a timeline. The page is divided into 3 sections vertically to group the different types of development activities: Ground Development, Tests, and Analysis, Robotic Missions, and Dedicated Flights. Each bar represents a task, and is color-coded by discipline. A key is shown in the bottom right.

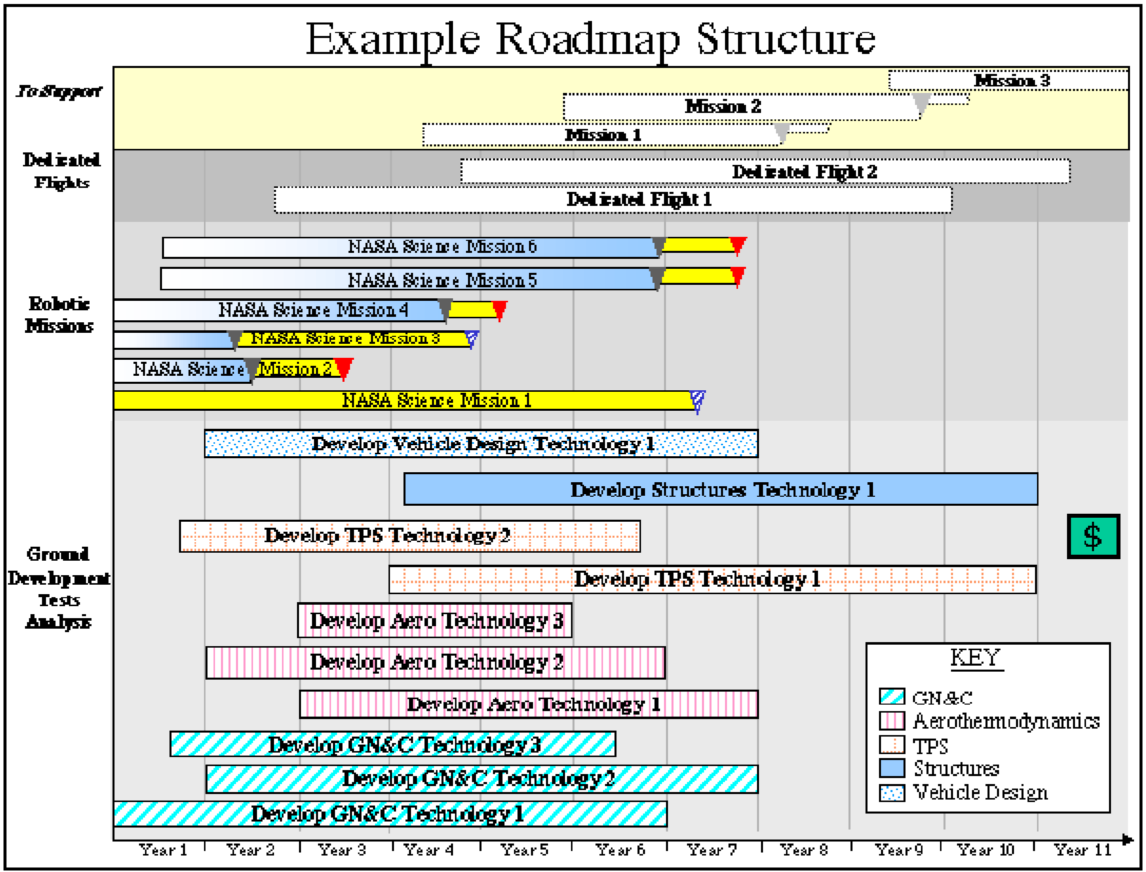
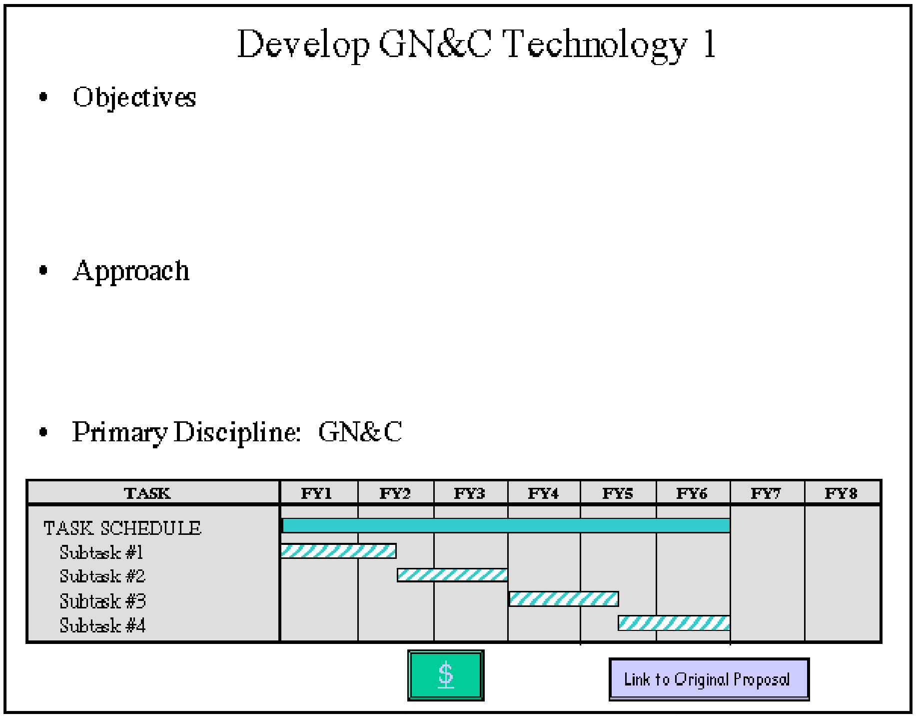


Figure 1 Example Top-Level Roadmap Slide

Task Description Slides

Subsequent slides in the electronic presentation are descriptions of each task; an example is shown in figure 2. Each task description slide has a title identical to one appearing in a task bar on the roadmap. The objective, approach, primary discipline, and a top-level schedule are shown on each task slide. The information on the task description slides is supplied by each task lead. At the bottom of the task description slide is a green box. This box is linked to the task budget (a Microsoft Excel™ Workbook file). Other links on the task description slide may go to proposals, more detailed task descriptions or schedules, test results, a work breakdown structure, or any other desired details.



Develop GN&C Technology 1

- Objectives
- Approach
- Primary Discipline: GN&C

TASK	FY1	FY2	FY3	FY4	FY5	FY6	FY7	FY8
TASK SCHEDULE	■	■	■	■	■	■		
Subtask #1	▨	▨						
Subtask #2		▨	▨					
Subtask #3				▨	▨			
Subtask #4					▨	▨		

Figure 2 Example Task Description Slide

Creating the Links within PowerPoint™

It is best to have all of the task description slides in place within the presentation file before creating the links to the roadmap task bars. Also, titling the slides to match the task bars will make the linking job easier. A simple example of link creation follows.

To link the descriptions to the graphical task bars, click on the task title in the bar on the roadmap slide ("Task 1", in this example). Go to the "Insert" menu, and select the "Hyperlink" item (see figure 3).

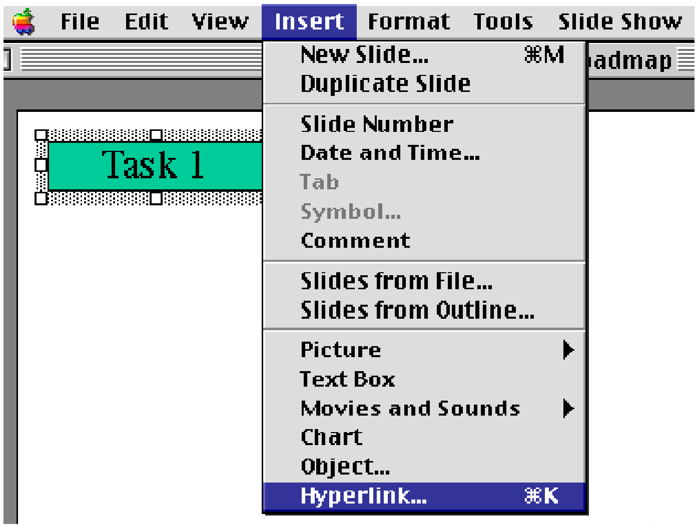
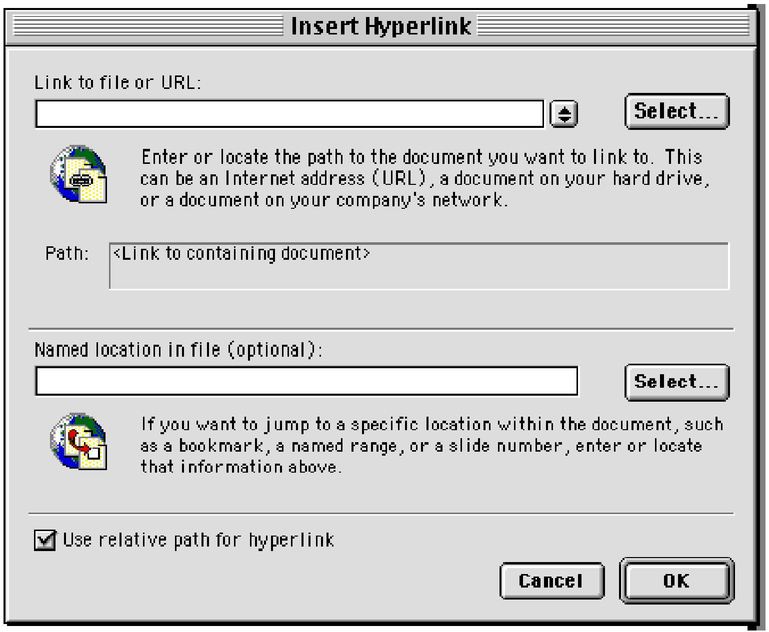


Figure 3 PowerPoint™ Menu Selection for Creating Hyperlinks

A menu will appear that allows you to specify the slide to which to link the task title (see figure 4). The lower entry in figure 4 is used to link to a slide within the current PowerPoint™ file.



Enter or locate the path to the document you want to link to. This can be an Internet address (URL), a document on your hard drive, or a document on your company's network.

Path: <Link to containing document>

If you want to jump to a specific location within the document, such as a bookmark, a named range, or a slide number, enter or locate that information above.

☑ Use relative path for hyperlink

Figure 4 PowerPoint™ Insert Hyperlink Menu

Click the "Select…" button, and a list of all slide titles within the presentation will appear. Select the slide that matches the task bar title and click "OK" (see figure 5).

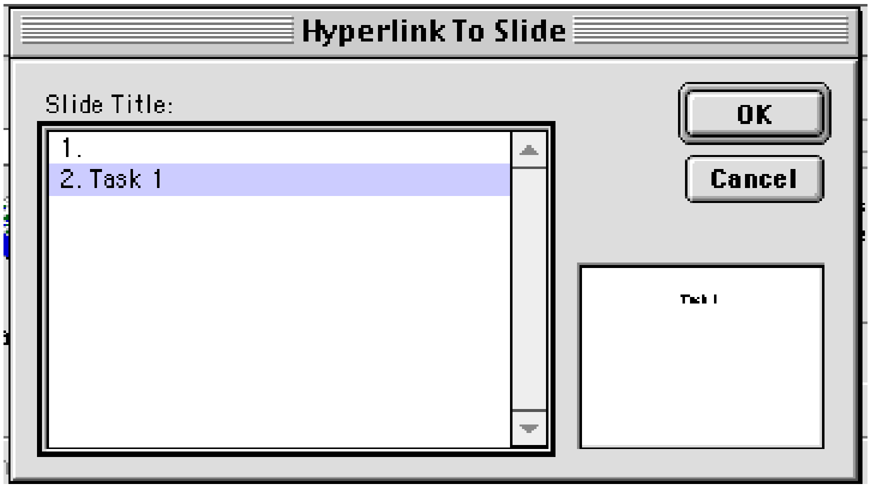


Figure 5 PowerPoint™ Slide Selection Menu

The hyperlink is now created, and when the presentation is viewed in Slide Show mode, the link will become active. When the cursor is passed over an active link, the icon will change from an arrow to a hand; again, this will occur only in Slide Show mode.

Creating the Links to Other Files

After the task descriptions are linked to the task bars on the roadmap, the basic roadmap structure exists and is ready for initial presentation. Information can be added to the task descriptions at any time, and the links will be undisturbed. The next step is to link the roadmap to information in other files. This is what makes the roadmap expandable.

As with any project, planning ahead is the easiest way to ensure your roadmap can easily evolve. The aeroassist roadmap consists of tasks within different disciplines, so the discipline category is an easy way to organize information. Another option would be to organize by the mission category that the task supports; however, some tasks can support more than one mission. The roadmap developer set up folders of files within an overall "Roadmap" folder. There is one folder for each discipline, and one folder for each task within that discipline. This makes it easy for task leads to determine where to add their information. Once a structure is decided, create the folders in the necessary hierarchy *before* creating any external links. An example folder hierarchy is shown in figure 6.

Once the folder hierarchy is in place (which actually only takes a few minutes, once planned), any existing information should be placed in its proper folder. For example, if there is a proposal document for Structures Task 1, it should be put in the Task 1 folder within the Structures folder. After all the information is in its proper place, the linking can begin. The steps are essentially the same as creating a link within the PowerPoint file. Determine the link to create; if the link is from a task description slide, you may have to create a box or other icon from which to initiate the link. Making sure you are not in Slide Show mode, follow the steps above, to figure 4. Once in the "Insert Hyperlink" menu, use the top entry, entitled "Link to file or URL". Click the "Select…" button, and a listing of the files on the computer's hard drive will appear. Locate the Roadmap folder with its underlying folder hierarchy, then the file you want to link (see figure 7). Click "OK".

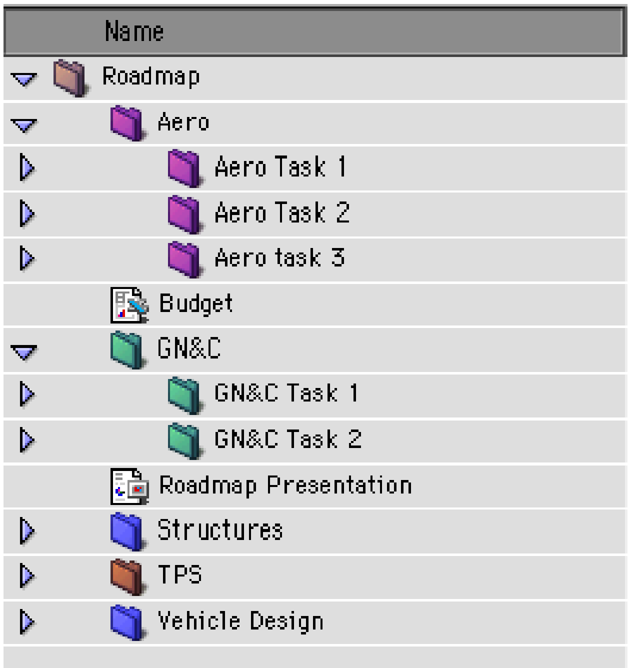


Figure 6 Example Folder Hierarchy

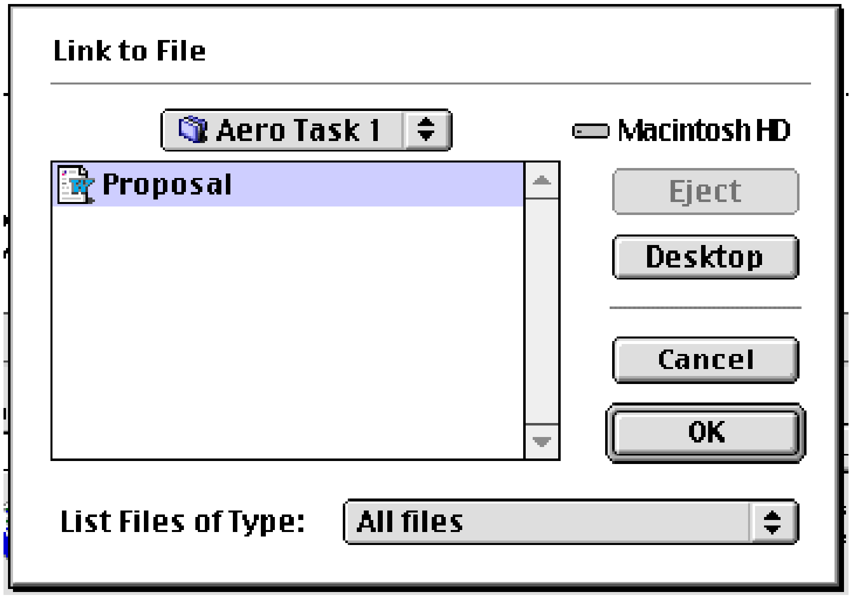


Figure 7 Selecting a File for Linking

The path to the file just selected will appear in the top box of the Insert Hyperlink menu, and the relative path to the file is shown below, in the "Path" box. Before clicking "OK" to exit the menu, be sure the box at the lower left has a check mark, indicating the use of a "Relative path for hyperlink" (see figure 4). This makes the entire Roadmap folder portable, so that as long as users maintain the folder structure within, the links will function.

Method Notes

This hyperlinked method is best presented electronically as opposed to viewgraphs. Using the electronic medium, the roadmap presentation can be highly dynamic. One issue can be the resolution of the projector if the roadmap becomes very crowded and the text and graphics are small. Another characteristic of the method is that it requires a large collection of files, and not just one file. In addition, the transmission between members can be an issue due to the overall size of the files. One solution for the large file size and number is file compression techniques. The AWG has successfully used the PKZIP™ utility (for PC users) and the StuffIt Deluxe™ application (for Macintosh users) to create a single file of roadmap information, which is then transferred to the group members. These files are downloaded by team members, then are self-extracted with the correct folder structure so that the links will function correctly.

CONCLUSION

Aeroassist is one of the key technologies necessary for both future robotic and human exploration missions. Aeroassist includes several different mission phases, and relies on advancements in several engineering disciplines. Once the current state of the technology is assessed, and future required mission capabilities are defined, a roadmap for technology development can be constructed. A tool, based on readily available commercial software, has been developed that allows for the creation of an effective, easy-to-manage technology roadmap. This tool allows discipline experts to plan their work, and for technology managers to assess the milestones and funding levels necessary to complete the development process. The NASA Aeroassist Working Group is using this tool to organize, present, and distribute its technology roadmap.

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