



Keeping the MSX on Track

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A large and multifaceted program such as the Midcourse Space Experiment (MSX) involves the interaction of numerous people at various facilities, including scientists, engineers, designers, fabricators, machinists, calibrators, and subcontractors. To determine the budgetary and time requirements for such an effort requires careful coordination. By using appropriate scheduling tools and reporting techniques during the various program phases, the MSX program was able to stay on track.

INTRODUCTION

Major DoD programs often encounter several obstacles, including redirections, funding problems, and delays, and the Midcourse Space Experiment (MSX) was no exception. The development of a spacecraft bus that was nearly a totally new design and the simultaneous development of 10 state-of-the-art instruments presented a constant challenge to meeting the launch date and staying within the budget. Successful completion of the program required the use of several innovative scheduling techniques.

As a rule, scientific and technical staff view schedules as something between a waste of time and a marginally necessary evil. Schedules are seen as a management cudgel used to browbeat people who could otherwise be doing “useful” work. The assumption is that the coordination of hundreds of people and multimillion dollar facilities is not useful work.

The effective management of a large and multifaceted program such as the MSX requires that accurate scheduling information be used for several purposes. First, a schedule allows the *plan* of the process by which

a task is to be accomplished to be visualized in a time-ordered fashion. This, in turn, makes it possible to *predict* accurately the time and resources needed to complete a task. In addition, a schedule provides a means by which the activities of individuals involved in a given effort can *communicate* their progress to others. Finally, schedules are used to *coordinate* the activity of all the various small teams of people so that resources are not over- or under-utilized.

Because of the variations in size and focus during the three distinct development phases of the MSX program, three very different approaches to scheduling were required. The first stage of spacecraft development followed the initial system engineering and mission design. In this first phase, all of the necessary subsystems were designed, breadboarded, built for flight, electrically and environmentally tested, and readied for integration with the spacecraft. The second stage of spacecraft development was more focused and determined the logical sequence of steps in the integration of each subsystem with the spacecraft. This stage cul-

minated in the environmental testing of the completed MSX spacecraft. Finally, the completed spacecraft was prepared for launch and orbital insertion from Vandenberg Air Force Base on a Delta II rocket.

SUBSYSTEM DEVELOPMENT

During the first phase, the efforts of 27 lead engineers and their teams needed to be coordinated with APL's Technical Services Department (TSD), which was doing the detailed hardware design and fabrication. Also, the spacecraft integration and test team anxiously waited for the delivery of each piece of hardware so that it could be integrated with the rest of the completed units. Subsystem activities were initially laid out in large blocks such as *design, test, fabricate, environmental test, and deliver*. Program and APL Space Department requirements were established for the necessary reviews prior to each phase of hardware development. Milestones were established for each subsystem for design reviews, fabrication feasibility reviews, and drawing release. The generic schedule used for each subsystem development is shown in Fig. 1.

The traditional schedules soon proved unsatisfactory for the MSX because of its large size and extensive resource needs. More detailed and accurate scheduling

information was imperative to allow work priorities to be set within TSD and because the integration team needed to know when each subsystem would be delivered.

The lead engineers developed process models for the subsystems that they were to produce. These models were constructed as critical path method (CPM) charts of all the tasks that had to be completed from initial design to delivery for integration (see the boxed insert at the end of this article). No attempt was made to allocate resources to these task networks, but a great deal of attention was given to establishing the expected duration of each task. Even more attention was focused on the logical relationship of each task to its predecessors and successors. In this way, bottlenecks were identified and, whenever possible, additional resources were provided. A portion of one of these process models is shown in Fig. 2.

To develop this information, weekly scheduling meetings were held to review the development of each subsystem in detail. Since the interaction of the development of each subsystem with development of every other subsystem was important, it was imperative that a representative of the program office and the program system engineer attend all of these sessions. Also, since the scheduling questions that arose in the meetings typically involved the allocation of resources within the

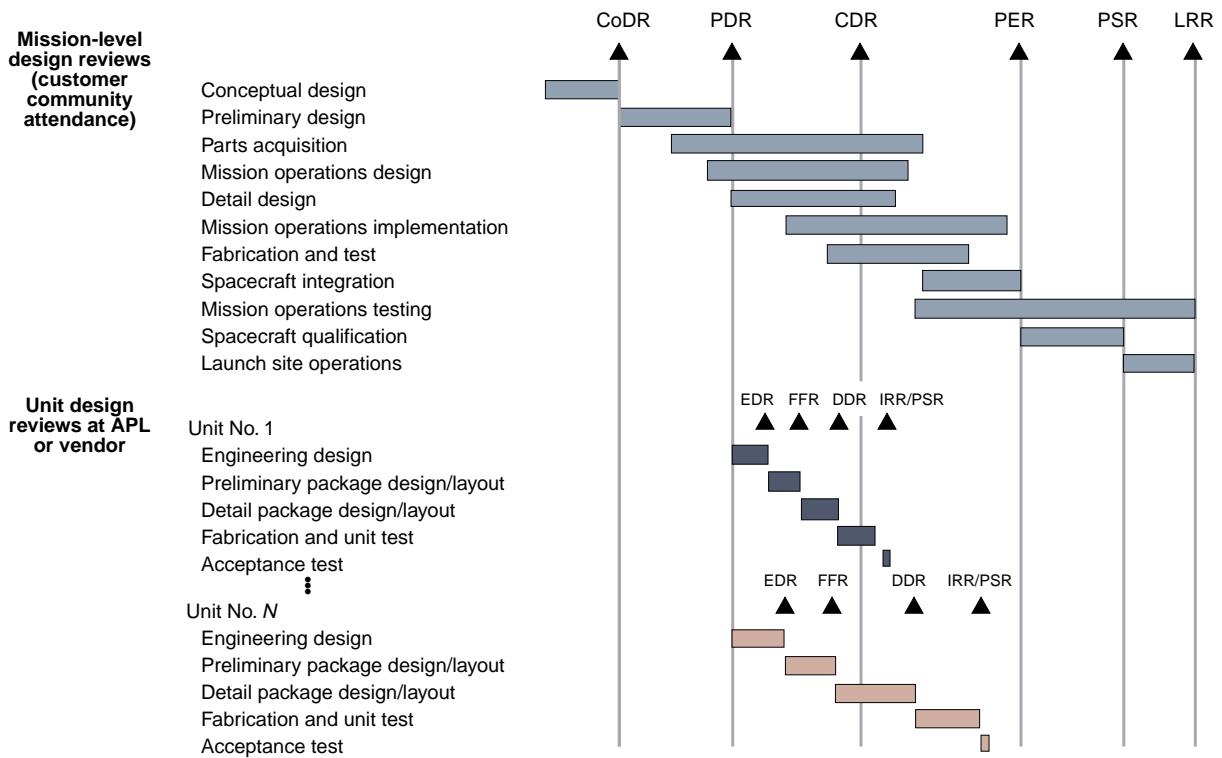


Figure 1. Generic schedule used to establish major milestones for the MSX program and for the development of each subsystem. CoDR = conceptual design review, PDR = preliminary design review, CDR = critical design review, PER = pre-environmental review, PSR = pre-shipment review, LRR = launch readiness review, EDR = engineering design review, FFR = fabrication feasibility review, DDR = detail design review, and IRR = integration readiness review.

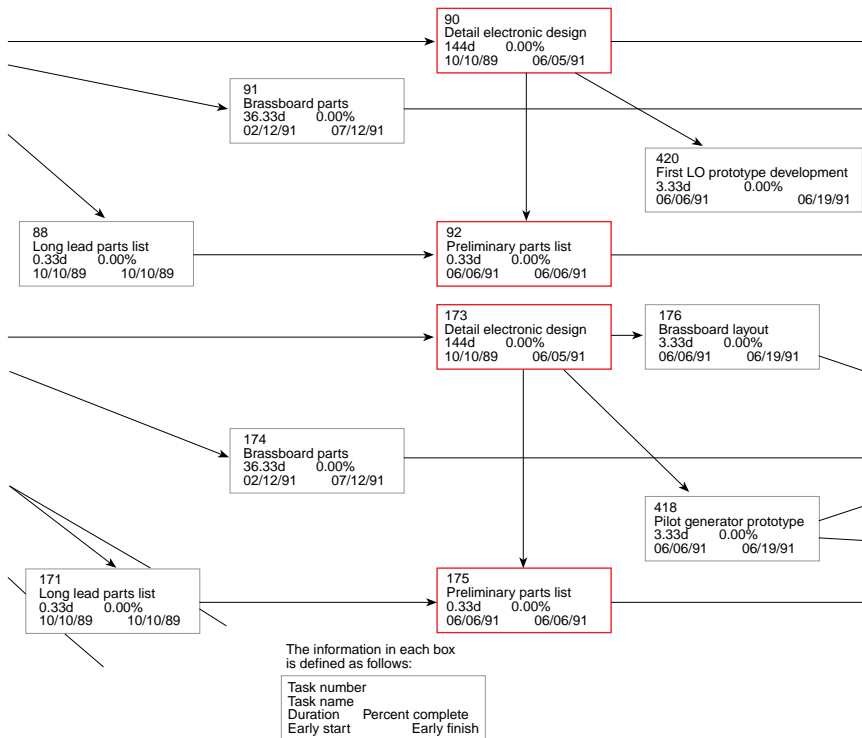


Figure 2. A segment of the CPM chart for development of the beacon receiver. Critical tasks are shown in red.

lead engineer's group and the resources of TSD, the group supervisor and a TSD coordinator, as well as the program shop coordinator, were always invited and typically attended these meetings.

The TSD coordinator and the program shop coordinator were dedicated to the MSX program during the major design and fabrication period. Their roles were to keep MSX hardware moving through the shops and to report on the status to their respective management. Their efforts were complementary. The TSD coordinator approached the task as a representative of TSD who was aware of all the non-MSX work that TSD was performing and knew TSD's procedures and processes. The program shop coordinator, however, was a member of APL's Space Department and was part of the MSX program management team. This person was aware of all current and predicted MSX tasks, their priorities, unique requirements, contact persons, and MSX unique attributes. Both coordinators were members of the various design review boards.

To make scheduling meetings truly effective, a projector was used with a desktop computer running the scheduling software. As progress was reported by the lead engineer, it was entered directly into the schedule. Resultant changes in expected dates of completion were immediately apparent to the entire group of people in the meeting, and the overall impact of any delay was easily recognized. Tasks were reordered and priorities were changed in real time, and the anticipated

results were predicted by the scheduling software. When necessary, changes to the basic model were made so as to accommodate desired completion dates. The wisdom, for example, of whether or not to work overtime on a specific task was easy to assess. By including line supervisors, the tasks and priorities of people within a specific group could be changed immediately.

Early in the program, the typical Gantt chart schedule was judged to be inadequate for coordinating the numerous development efforts taking place. The first phase required several schedules, each of which was intended for a relatively small number of people. At the same time, a mechanism was needed to coordinate the activities of many people working on several different tasks. To do this, a CPM chart was needed for each subsystem. The real predecessor–successor relationship for each activity needed to be established at a relatively detailed

level. The question of how small a task was sufficiently detailed for the purpose of these process models was asked many times. A rule of thumb was adopted that a man-month of effort was sufficiently small. More detail typically meant describing the activity of a single person performing functions with no interaction with others. Reporting progress at this level was clearly adequate. More than a man-month normally meant that some external interaction could be anticipated during the activity, and, therefore, some added detail was useful. CPM charts were essential for determining when the development of a subsystem would be resource-limited or when the delayed completion of a task would have a deleterious effect on other tasks. They were the major means of keeping the development of the MSX on track.

These detailed schedules, which included more than 8000 activities, provided continuous guidance during fabrication, testing, and spacecraft integration to ensure that the delivery requirement would be met. The information was also useful to the functional group supervisors in predicting when people would be available to assist in other areas and when certain activities needed more attention. Although resource allocations were not made a formal part of the process models, they were used extensively for assigning people to various tasks.

The spacecraft integration schedule was used to establish completion dates for all subsystem development. From an initial integration flow diagram, an integration

process model was developed that eventually grew to more than 1000 activities. This schedule was reviewed in the same manner as the subsystem development schedules and was used to determine shop work priorities, environmental testing priorities, and the effects of alternative solutions as difficulties were encountered. The dates for the delivery to the Goddard Space Flight Center (GSFC) for environmental testing, Vandenberg Air Force Base for prelaunch preparation and mating with the Delta II vehicle, and launch were kept fixed as endpoints of this schedule until external circumstances forced a change. By constantly searching for means in which operations could be done in parallel or in a different sequence, schedule delays were usually avoided. However, funding problems or major subsystem delays forced some adjustments to these key milestones. By keeping the integration and test schedule as a CPM chart, the impact of such changes on all the details of the program could be quickly assessed.

INTEGRATION AND TEST

After integration of the major spacecraft subsystems, a change occurred in how scheduling information was used, and, consequently, the format in which it

was presented also changed. No longer was the program office dealing with a wide and disparate group of lead engineers trying to use the same set of resources. During final integration at APL and environmental testing at GSFC, activities were focused on the spacecraft and the human resources that had to be coordinated to perform specific functions at a given time. Although the CPM network continued to be the underlying structure upon which the schedule was built, it was no longer adequate as a means of task coordination and communication of information to the staff.

It is difficult for people to determine their tasks and deadlines from a network of hundreds of activities. Consequently, the Gantt chart, derived from the CPM network, was used as a principle means of communication during the final test phase at APL and throughout GSFC environmental testing.

The use of a Gantt chart at this stage proved advantageous because it showed when a particular activity was scheduled to occur. However, the causes and effects of delays were no longer apparent. Thus, the underlying CPM network was continually maintained by the program office, but communication with the integration and test team was accomplished with a Gantt chart. A representative chart from the integration phase of the program is shown in Fig. 3.

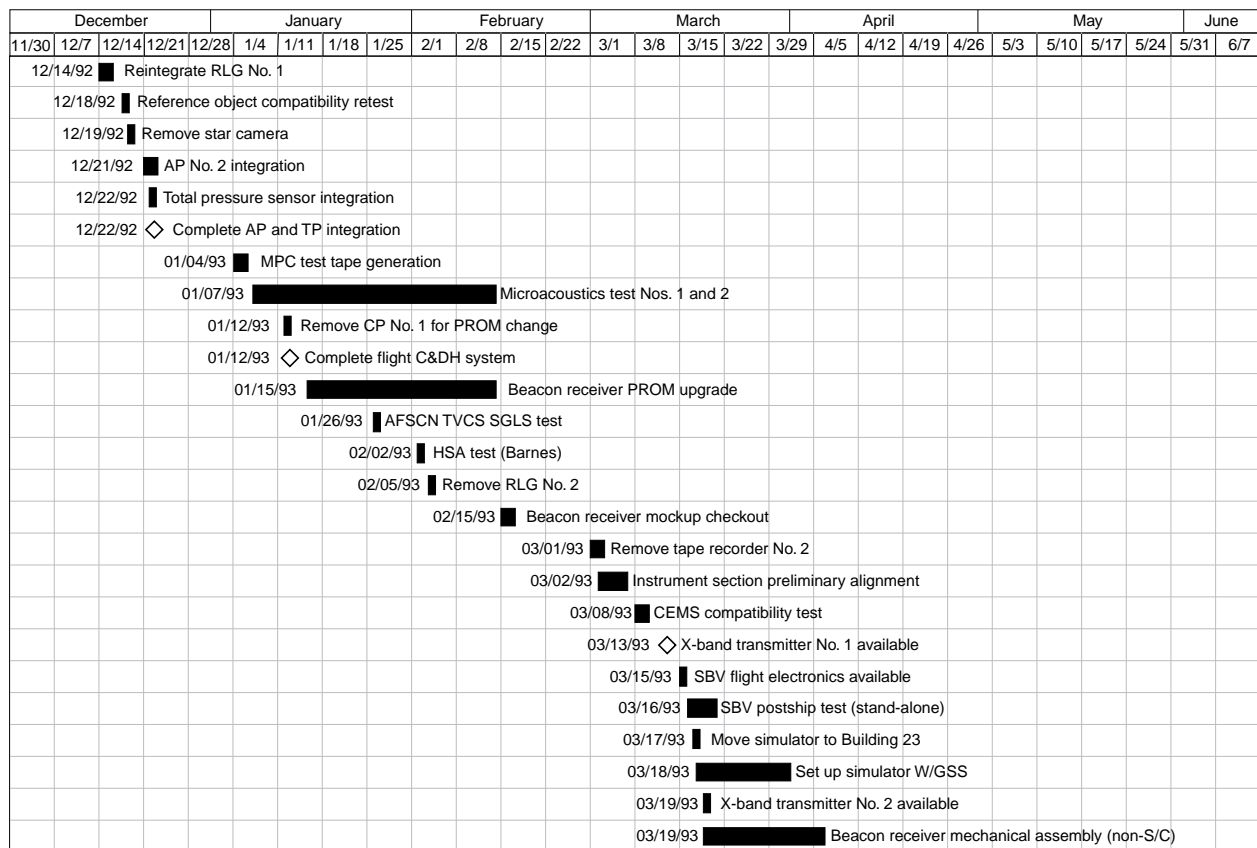


Figure 3. A typical Gantt chart showing a portion of the spacecraft integration activity. The diamonds indicate milestone events.

LAUNCH SITE PROCESSING

During launch site processing, it became apparent that yet another form of schedule presentation was required. Activities at this phase tended to be much more serial because each major test had to be completed before the next could begin. Personnel became much more interested in what activity was scheduled for a particular day of the week rather than how long it was going to take or what they were likely to need to do next month.

To address these scheduling needs, a program calendar was implemented. The fundamental scheduling information was still maintained with a CPM network where all the task dependencies could be taken into account. Gantt charts were still printed from this information so that long-term planning could be accommodated. But for day-to-day communication with the test team, a calendar that reflected the same information, but in a more easily understood format, proved to be invaluable. A typical example is shown in Fig. 4.

During the final phase of spacecraft processing when the spacecraft was at the launch site and was being

prepared for mating with the launch vehicle, the calendar format continued to be the most effective method of keeping all the various groups of people and activities coordinated. Just as was done at GSFC, a CPM network was maintained to capture task dependencies, Gantt charts were used to coordinate the activities of the various groups with the major activity flow, while the calendar showed the daily work plan.

Since planning at the launch site was particularly critical, the time span of the calendar was reduced to just two weeks, and updates were issued weekly. In this way, the entire team knew of all planned activities at least one week in advance so that conflicts could be addressed in time to avoid delays.

At this point in the program, the previously mentioned rule of thumb (activities at the man-month level being of interest) obviously was no longer valid. Activities were often scheduled at a detail level of *one hour* of activity if they involved exclusive use of the spacecraft, if they were hazardous operations that would restrict access to the spacecraft, or if they were critical to the final preparations of the spacecraft.

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
<i>September 25</i>	<i>September 26</i>	<i>September 27</i>	<i>September 28</i>	<i>September 29</i>	<i>September 30</i>	<i>October 1</i>
Transport cryo GSE to SLC-2	S/C performance test 0052 begins @ 0800 Battery capacity test GSE/MCC communication verification		Transport cryo GSE to PPF and reconnect		LAr fill SPIRIT III special test	Solar array flood test No. 1 AFSCN compatibility test 0064 dry run AFSCN compatibility test 0064 0800-1700 Beacon receiver test
Spacecraft checkout w/...	MDA cryo GSE pathfinder on SLC-2				SPIRIT III burst disc/can replacement	
Battery 72-h retention test				S/C alignment test 0062		
				S/C performance test 0052 w/solar array		
				RF clearance OP No. W3632		
<i>October 2</i>	<i>October 3</i>	<i>October 4</i>	<i>October 5</i>	<i>October 6</i>	<i>October 7</i>	<i>October 8</i>
MOST test 0058 begins @ 1700 MOST test preps Stimulators removed for alignment	Simulated launch @ 0454 PDT Connect cryo heaters GSE/MCC communication verification	Checkout cryo heaters	H ² detection system demonstration H ² transfer system test MCC-TSC-1 connectivity test 0059 2100-2300 PDT	MIT/LL remove red tags—install green X-band gimbal test (3 h) PPF power shutdown (4 h) 0800 PPF end-to-end emergency vent purge test Flight dust cover fit check Transport blockhouse GSE to SLC-2	Remove S/C GSE cables, etc. LAr fill Disconnect cryo modules Dump cryogen	Reconnect cryo modules S/C weighing operations Warm cryostat to 35 K
S/C alignment test 0062						
				RF clearance OP No. W3632		
				MOST test 0058		
				H ² cryo prefill checks/leak checks		
				Install ITO/Ag/FEP surfaces		

Figure 4. A typical program activity calendar showing tasks to be performed on specific days.

CPM VERSUS GANTT

A critical path method (CPM) chart is a means by which the activity flow of a given process can be modeled. It is constructed by defining each activity that must be completed for a given process and a corresponding duration for that activity. Individual activities are then "linked" to those activities that must be completed before a given activity can begin. Normally, a CPM chart is constructed without assigning dates, except when an activity is specifically constrained for external reasons to occur at some specific time (e.g., a promised delivery date). By linking all the activities required for a process to be completed, the earliest possible start date for each activity can be determined. Also, the latest possible date for each activity to be completed without affecting the completion date can be determined. The difference between the earliest and latest possible completion dates is defined as the "slack" for that activity.

The completed CPM chart becomes a graphic model of the given process. However, it does not easily convey information about the time sequence in which activities are expected to be performed. That information can be gleaned only from the text within the boxes.

The Gantt chart is merely a means to present scheduling information. It shows graphically the calendar duration for each task to be performed, but conveys no information as to what must be accomplished before a given task can begin. Consequently, the impact of the delayed completion of a given activity on any other activity is not readily apparent.

Attempts have been made to use time-ordered CPM charts and linked Gantt charts, but these have proved cumbersome at best.

of scheduling: CPM charts were used to *plan, predict, coordinate, and control* the efforts of several teams drawing on the same resources, Gantt charts were used for the same functions when the efforts became focused on a serial set of tasks, and task calendars were used when many activities needed to be completed nearly simultaneously and thus the probability of conflict was high.

By using these scheduling tools for the MSX program, APL's TSD was able to produce 115 multilayer printed circuit boards for engineering models and 292 multilayer printed circuit boards for flight. Also, the Space Department was able to fabricate 14 subsystems and 9 instruments with a total of 54 processor units (40 in APL-built hardware, 3 in attitude sensors, and 11 in government funded procurement sensors), and the integration and test team was able to maintain a firm launch date for approximately 1 year after the establishment of the delivery date of the Spatial Infrared Imaging Telescope III (SPIRIT III) sensor up to the time of the sensor cryostat failure. For such a large and complex spacecraft, this accomplishment is attributable to the management process that was used, of which scheduling was a significant part.

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SUMMARY

Three means of presenting scheduling information were used for the MSX to accomplish the four goals

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