THE SCHEDULING EFFICIENCY FOR THE HUBBLE SPACE TELESCOPE DURING THE FIRST YEAR OF OPERATION

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Introduction

Prior to the launch of the Hubble Space Telescope (HST), estimates were made as to the ability of the Science Operations Ground System (SOGS) to schedule observations efficiently. These estimates ranged from the extremely pessimistic (0%), for those who thought SOGS incapable of the task, to optimistic values around 35%. These latter estimates were based on several factors including the ability of HST to see the Tracking and Data Relay Satellites (TDRS), the penetration of HST's orbit into the South Atlantic Anomaly (SAA), target visibility, etc. HST completed the Orbital Verification (OV) phase of the mission in November 1990 and is currently in the Science Verification (SV) portion. Although the observations made during these early phases are not, in general, representative of the majority of the mission, they are indicative of the scheduling software's ability to cope with many of the extreme cases likely to be seen during the mission. This paper presents the results of the first year of scheduling observations on HST.

General Overview of Scheduling Efficiency Since Launch

Shown in Figure 1 is the total scheduling efficiency since launch (shown as the (percent) fraction of time during which the spacecraft performed some activity relative to the total time span of a given calendar). These activities include the total alignment time for each separate observation as well as numerous overheads (e.g., guide star acquisitions, target acquisitions, FHST updates, etc.). The efficiencies of the calendars generated by SPSS in this period range from a low value of 13% to a high of 62% with the majority of calendars falling in the 37-47% range. There are several features about these efficiency plots which need to be pointed out at this time. First, very early scheduling operations for HST were different than has been true more recently, both in terms of the type of proposals being scheduled as well as the time spans of the calendars. Characteristic of the first 20 days or so of scheduling are short interruptions between calendars created at STScI. These calendars contained planned gaps during which teams of engineers and scientists would analyze data and then upload new information to thespacecraft. During these gaps, spacecraft attitude was maintained by "Health and Safety" SMSs (Science Mission Specifications) generated by the Payload Operations Control Center (POCC) at the Goddard Space Flight Center. Second, there are visible gaps in between calendars which are of a longer duration (on the order of 1-3 days). These are spacecraft safing events, times during which the spacecraft placed itself in a mode wherein it could not be damaged. Note that most of the safing events which have so far occurred happened within the first four months of operations, although two other events have happened fairly recently. Also, note that these do not include individual science instrument (SI) safing events. SI safing events do not affect the overall functioning of the spacecraft, just the ability to perform observations with that instrument. Because the instrument is only recovered once the safing event has been fully analyzed and at such a time that the recovery can be performed without disrupting the operation of all the other instruments, these SI safing events are not visible on these plots. Third, early calendars generated by SPSS were of short duration (~18 hours to several days), whereas the current schedule (one expected to last for the duration of the mission) is to produce calendars covering seven days and running from Sunday midnight to Sunday midnight. This is driven not due to limitations in the ground support software, but because of the scheduling time periods for TDRSS. Finally, we wish to address how the actual observing timeline has reflected the timeline planned prior to launch.

Originally, the OV period consisted of two equal portions, covering a four week period, during which the Marshall Space Flight Center was to have control of the spacecraft in the first half and Goddard Space Flight Center was to have control in the latter half. This orbital verification phase was intended to be used to check out the general health of all onboard support systems (the batteries, solar panels, on-board attitude control, etc.) as well as an initial checkout of the general health of the SIs. This period was to be followed by an eight month period of science verification (SV) during which the various operating modes of the SIs would be checked out. Shown above Figure 1 (and all subsequent plots) is the planned duration of OV and SV as well as the original planned start of the GO/GTO (General Observer/Guaranteed Time Observer) program. Also shown is the actual duration of OV and the beginning of SV. Although OV officially ended 202 days after launch (on Nov. 12, 1990), some portions of OV were still being executed until very recently. Likewise, several SV proposals began to be executed some 60 days or more prior to the official beginning of SV (as the initial OV checkouts of some instruments were completed before others). The current timeline plans for the end of SV to be sometime late in 1991. There are several reasons for the extension of both the OV and SV phases of the mission. First, several

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weeks of activity were involved in attempting to focus the telescope. Once it was discovered that the aberration of the mirror was to blame for the inability to find a single optimum focus, it was necessary to continue to

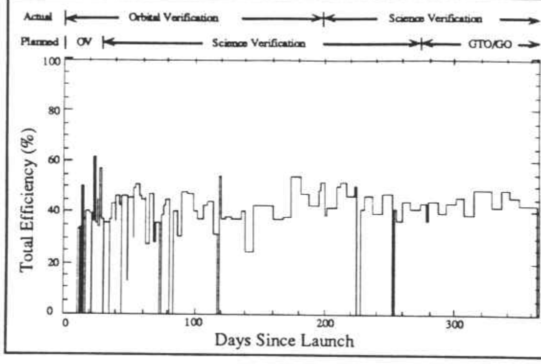

Figure 1.
The total efficiency of calendar scheduling performed by the Science Planning and Scheduling System portion of SOGS. The efficiency is plotted as the (percent) fraction of time during which the spacecraft performed any activity relative to the total time span of the calendar.

perform observations with the WF/PC and FOC to determine the amount of aberration so that a point spread function could be determined. This greatly expanded the duration of OV. In addition, it was decided to perform several observations for early release to the astronomical community and the media in order to provide evidence of the capabilities of the telescope in spite of the spherical aberration.

Time Spent in Various Activities

Included in Figure 1 are several different activities which are overhead activities. These are such things as target and guide star acquisitions, FHST updates, and slews and settling time. Several of these activities are broken out in the following figures. There are three main types of observing activities into which a calendar can be broken. These are main fixed observations (these include not only targeted observations but internal and earth limb observations), interleavers (activities which do not alter the attitude of the spacecraft and so can be scheduled during large gaps within a scheduling unit of another observation), and parallel observations. So far, interleavers have only been used on a few calendars (fewer than 20) and have accounted for less than 5% of the total time span of any given calendar. In addition, the current version of the ground-support software does not support the use of parallel observations. Therefore, these are not presented herein. Figure 2 shows the amount of time spent on each calendar in main fixed observations. Main fixed observations account for the majority of the total time presented in Figure 1. The amount of time since launch spent in main fixed activities (essentially the total of all the individual alignment times) has ranged from a low of 12% of the calendar span to a high of 52% with the bulk of the calendars ranging from 25- 30%. Little difference is seen in the efficiency between the OV period

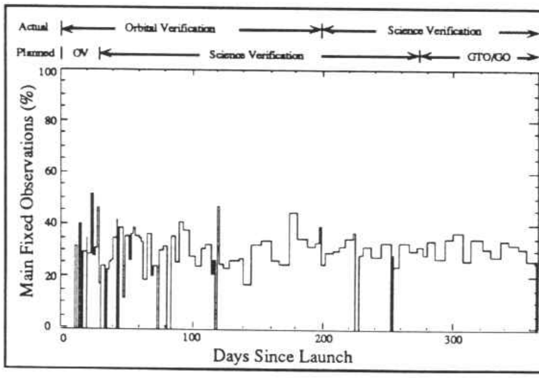

Figure 2.
The efficiency of main fixed observations as scheduled by the SciencePlanning and Scheduling System portion of SOGS. The efficiency is plotted as the (percent) fraction of time during which the spacecraft performed targeted, internal, and earth-limb observations relative to the total time span of the calendar.

(where much of the observing timeline was determined by committees of individuals) and the SV period to date (where the timeline is "optimized" by the use of the artificial intelligence program SPIKE). Shown in Figures 3-5 are the percent time spent per calendar in the (re)acquisition of guide stars, the (re)acquisition of targets, and in slews and settling, respectively. Important to note in Figures 3 and 5 are the relatively consistent amount of

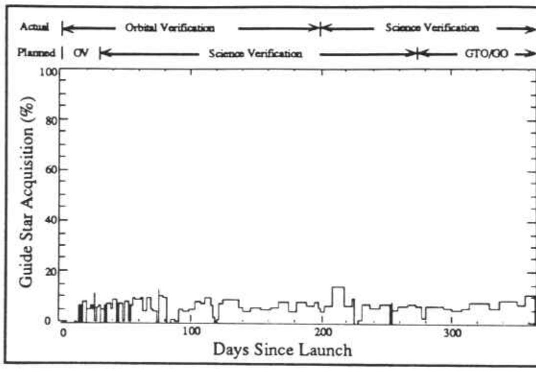

Figure 3.
The amount of time spent in guide star (re)acquisition for calendar spanning the first year of observations by HST. The time is plotted as the (percent) fraction of time which the pointing control system (PCS) spent acquiring or reacquiring guide stars relative to the total time span of the calendar.

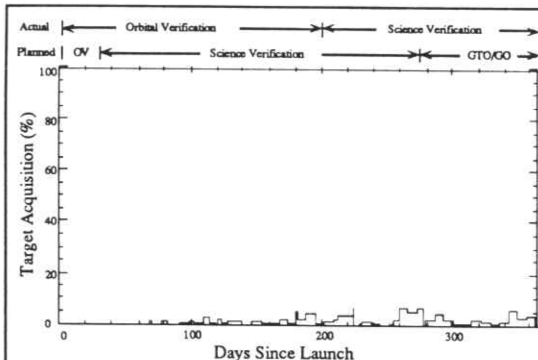

Figure 4.
The amount of time spent in target (re)acquisition for calendars spanning the first year of observations by HST. The time is plotted as the (percent) fraction of time which the pointing control system (PCS) spent acquiring or reacquiring targets relative to the total time span of the calendar.

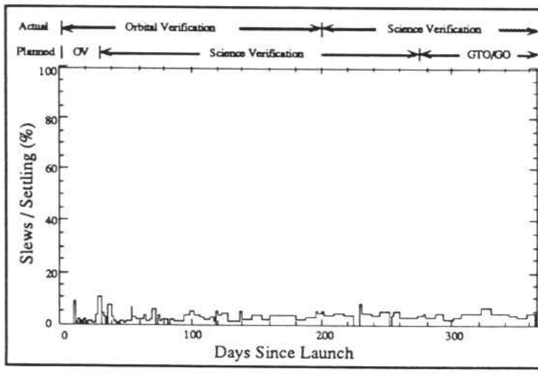

Figure 5.
The amount of time spent in slewing the spacecraft for calendars spanning the first year of observations by HST. The time is plotted as the (percent) fraction of time which the spacecraft spent slewing relative to the total time span of the calendar.

time spent in performing guide star acquisitions and in slewing the telescope (~5-10% and ~5%, respectively). Most of the variation of these three activities can be attributed to the amount of time spent pointed at a particular target, as well as the number of internal observations scheduled on a given calendar. Figure 4, however, shows one of the primary differences between OV and SV activities, that is that much of the early OV observations did not require much time for target (re)acquisition. Much of the early timeline involved remaining at a particular attitude for extended periods of time, but few targets were actually involved. This was necessary to perform many of the checkouts of the pointing control system (PCS) which is involved not only in slewing and guide star acquisition, but in maintaining attitude. Target acquisitions have become a larger fraction of the calendar activities as the spacecraft spends more time in instrument checkouts and can probably be expected to account for 5-10% of the calendar time as a norm. Not shown is the amount of time spent performing updates of the fixed-head star trackers (FHSTs) which accounts for less than 3% of the total calendar time.

The Impact of TDRS Contact Time on Efficiency

Another quantity which has a potential effect on scheduling efficiency is the amount of time required by a calendar to be in contact with one of the two Tracking and Data Relay Satellites (TDRS). The Tracking and Data Relay Satellite System (TDRSS) is the sole means of communicating with the spacecraft. The amount of time required for an observation and the availability of time on a given TDRS, as well as the ability of HST to see the TDRS, can have a significant impact on it's schedulability. SPSS can take all of this into account, but all final resolutions of conflicting requests for TDRSS time must be resolved between POCC, STScI, and the NCC (Network Control Center). The NCC is responsible for scheduling time on TDRSS. Shown in Figure 6 is the percent TDRSS request time for HST to date. Note that this is not the amount of time given to HST during final conflict negotiations nor does it take into account the additional time for monitoring the spacecraft which is requested by POCC nor the time allocated on an emergency basis during spacecraft safemode events. This time does include the total amount of time required by the calendar for uplinks requested by the institute (for spacecraft and SI commanding), downlinks requested for real time activities (e.g., interactive acquisitions), and decision time needed by the observer. Only a minor fraction of the total calendar time (<<1%) is taken by decision time. Note that during early OV, a large fraction of time was needed to perform the necessary spacecraft commanding and to obtain data. During the latter portion of OV, however, and into early SV, requested TDRS time has settled down to a nearly constant rate of ~5%. There is very little correlation, however, between the overall efficiency of a given calendar with how much TDRS time is requested (cf. Figures 1 and 6). Shown in Figure 7 is the amount of time during which either TDRS east was not available (generally during shuttle missions) or that TDRSS was

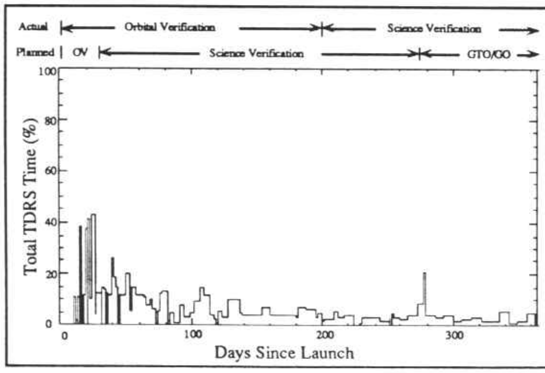

Figure 6.
The amount of TDRS contact time requested by the Science Planning and Scheduling system to support observations. The time is plotted as the (percent) fraction of total TDRS contact time (for real-time acquisitions, decision time, SI commanding, and data transmission) relative to the total time span of the calendar.

down (for upgrade or maintenance). TDRS east has the largest potential impact because during shuttle missions it is used exclusively for communications between the shuttle and mission control. These dead zones were calculated as a percentage of the total available TDRS east visibility during the span of the calendar. Note that during each time that a shuttle mission was launched or expected to take place, TDRS east was completely unusable for spacecraft like HST. Smaller periods of TDRS unavailability (varying from around 2 to 6 hours) are usually the result of maintenance or upgrade of equipment or software at White Sands. These have little effect, however, on the overall efficiency of calendars (as can be seen by comparing Figures 1 and 7). This is because many observations requiring TDRS can be satisfied by simply requesting time on the remaining TDRS (for which there are no extensive periods of dead time) or by scheduling the observation during an earlier or later time for which the TDRS down time is not a problem. This is a quite convenient feature of the manner in which the telescope is operated, since launch delays in the shuttle manifest can affect several weeks of TDRS east availability.

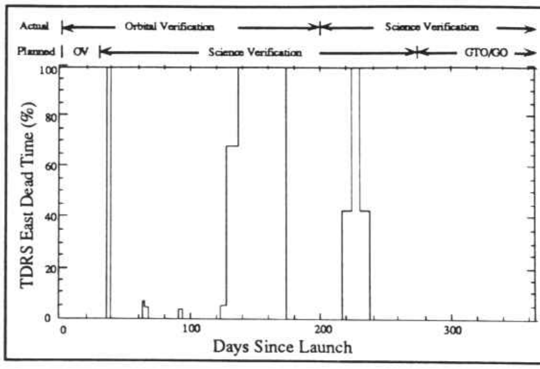

Figure 7. The amount of TDRS East dead time as experienced by HST through day 220 of operations. The dead time is plotted as the (percent) fraction of TDRS East dead time relative to the total TDRS East visibility time during the calendar. TDRS East unavailability after day 220 are not shown in this figure.

Data Volumes

The last topic to be examined is the amount of data so far generated by HST. This has a direct bearing on the efficiency of scheduling observations since one can very efficiently schedule activities on a spacecraft, but if no useful science activities are being performed or no data are being transmitted to the ground, it isn't a very efficient system. Shown in Figure 8 is the expected average daily data volume (in Gbits/day) for each calendar as calculated by the SPSS scheduling software. Note that this and the subsequent figure do not represent the actual data return of HST, but are expected returns. Very little data were being generated early in the mission. Figure 8

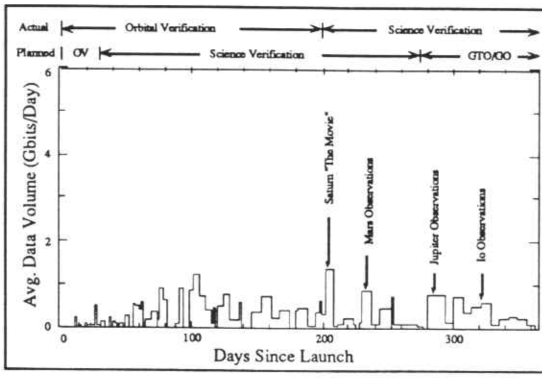

Figure 8. The average daily data volume (in Gbits/day) as estimated by the Science Planning and Scheduling portion of SOGS.

has denoted on it four special observations, the first a "movie" of Saturn's white spot which occupied a major portion of one calendar, the second a series of Mars observations, the third several scheduled observations of Jupiter, of which all but the first acquisition failed, and lastly some exposures of Io. Most of the early larger features were either the result of repeated data takes with the WF/PC and/or FOC to characterize the mirror or to support the early release observations (EROs). Shown in Figure 9 is the anticipated maximum daily data volume (to the same scale as Figure 8) for each calendar. Note the large peak for the Saturn movie. Even with this large value, however, HST has still not generated the amount of data expected on a daily basis once the observatory is fully operational (somewhere in the neighborhood of 6 Gbits/day).

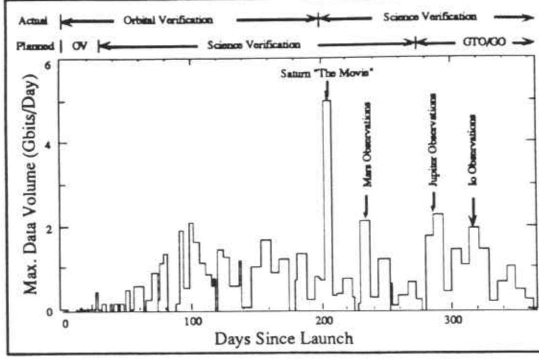

Figure 9.
The maximum data volume during each calendar (in Gbits/day) as estimated by the Science Planning and Scheduling portion of SOGS.

Summary

The scheduling efficiency of SOGS has so far supported the most optimistic estimates made prior to the launch of HST, around 30-40%. The overhead for each calendar amounts to some 15-20% necessary for supporting the science (guide star and target acquisition), a figure which is unlikely to change much during the course of the mission. It is expected that the overall efficiency of these calendars will improve from these values as more interleaver activities are available for inclusion and as SOGS is modified to support parallel observations. TDRSS availability, although not a major impact on the efficiency of a given calendar, can affect whether or not a given proposal will schedule during a particular period, and the TDRS time required by a given proposal can, of course, make the difference between an observation which is easy to schedule and one which is impossible. In addition, although no evidence currently exists to support the claim that artificial intelligence pre-scheduling of observations can improve the efficiency (this may be due to the largely manual effort still required to schedule many of these early observations) it may be that this will change as the nature of the proposals being scheduled have more to do with the more "normal" GO/GTO observations.

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