Summary: This document provides HST General Observers with the information needed to understand the implications of operating the observatory with fewer than three gyroscopes. This primer is divided into two parts: (1) a listing of the scheduling and performance impacts of operating in reduced gyro mode (RGM), and (2) a discussion of how pointing and target acquisition have been previously performed with HST and how they work in RGM. It is important for Observers to understand that the primary consequence for HST of RGM is in decreased efficiency and reduced flexibility in scheduling. All Observers should read Section 1 (the “what”) to understand how to prepare their proposals and to work with their Program Coordinators. Section 2 provides some background for Observers to better understand how HST operates and the resulting constraints of RGM (the “why”). A note on nomenclature: “reduced gyro mode” is also sometimes referred to as “one gyro science.” These terms of functionally interchangeable for an observer.

Section 1: Consequences of operating HST in Reduced Gyro Mode (RGM)

1.1 Overall outlook
For the majority of the observing program, HST will continue to provide the same quality science and offer the same set of observing capabilities. The primary impacts of operating in RGM are increases in scheduling constraints and decreases in overall efficiency. Our confidence in these predictions is based upon experience with RGM in 2005-2009. Current expectations are that HST will continue to have at least one functional gyro until the mid-2030s (the consequences of operating on one versus two gyros are insignificant).

1.2 Science quality
The stability of HST pointing is unchanged in RGM with respect to current jitter performance in three gyro mode (3GM). That is because since May 2021, HST pointing has used a hybrid of 3GM and RGM; when not fine guiding, the pointing control system uses 3GM, and then once guide stars are acquired, and during fine guiding and science exposures, the pointing control system (PCS) uses RGM. In RGM, the Fine Guidance Sensors (FGS) provide direct input to the pointing control law in the V2 and V3 axes of the observatory, while a single gyro provides input for the V1 axis (i.e., roll control). Thus, fully transitioning HST to RGM will only impact the pointing control system outside of science exposures. In 2007, comparison of RGM vs. 3GM performance showed a very small (1-2mas) increase in jitter. In the absence of the small pixel ACS/HRC channel, this results in no measurable impacts on image quality. Potential impacts of coronographic observations or observations with the narrowest STIS slits might exist but are probably less than the existing impacts from PSF variations due to small optical shifts in the telescope (i.e. “breathing”).

1.3 Reduction in the Field of Regard
Historically HST was able to observe approximately 82% of the sky at a particular time, with the primary limitation being the requirement to avoid pointing within 50 degrees of the sun (increased to 54 degree several years ago due to Gyro-3 instability). In RGM, this sky coverage is significantly reduced, as the
solar exclusion angle increases to 62.5 degrees, and target acquisitions must be performed while the fixed head star trackers (FHSTs) mounted on the shaded side of HST (see Section 2.2 and Figure 3) have a view of the sky not blocked by the Earth. The net result is that approximately 40-50% of the sky will be visible on a particular day. The remaining field of regard will shift over the course of the year (due to the motion of the Earth around the Sun) and shift between favoring northern to southern declinations with the 56 day precession of HST’s 28.5 degree inclination orbit.

This has three distinct impacts on planning and scheduling science observations: (1) a transient or coordinated event is less likely to be observable, (2) long sequences of observations are more difficult or impossible to schedule, and (3) observing strategies that interchange the ACS and WFC3 fields of view at six-month intervals are not practical. Figure 1 illustrates the 3GM and RGM field of regard for a particular day.

![Figure 1: Blue areas indicate the region accessible for HST observations on a given date. The distribution of available pointings shifts North and South with the 56 day precession of HST’s orbit. The solar exclusion and the overall visibilities drift over the year.](image-url)
Observers are strongly advised to avoid scheduling constraints that are not absolutely mandated by their science requirements. Absolute or relative timing requirements (e.g. WITHIN, AFTER) and orientation constraints (ORIENT, SAME ORIENT AS) are likely to significantly reduce scheduling opportunities or make observations infeasible in some instances. The APT tool provides a partial view of the consequences of these requirements, but observers are reminded that other programs may require the same limited opportunities, forcing some observations to be considerable delayed.

1.3.1 Observations with absolute time constraints
A current strength of HST is its ability to respond to transient events or to coordinate observations with other observatories and missions. RGM will limit field of regard and thus decrease such opportunities.

1.3.2 Long observation sequences
Observations requiring multiple visits spanning several months or longer are more difficult or impossible to schedule. Exploration with APT and consultation with STScI Program Coordinators is advised prior to proposing such observations.

This will also impact programs requiring the use of a fixed roll angle over a significant period. Again, exploration with APT is recommended.

1.3.3 Tiled or swapped ACS and WFC3 observations
Previously, an efficient observing strategy was to use ACS and WFC3 in parallel and return to the same fields after ~6 months with a 180-degree roll to improve efficiency (e.g., for the Frontier Fields program). This is not possible in RGM.

1.4 Additional constraints and prohibited modes
RGM unfortunately removes several science capabilities: (1) sun angles <62.5 degrees, (2) gyro pointing control, (3) moving target tracking and spatial scans faster than 5 arcsec/second, (4) guide star handoffs, (5) multiple acquisitions within a single orbit, (6) range of possible orients.

1.4.1 Sun Angle increase to 62.5 degrees
While this is primarily a scheduling efficiency constraint, it does preclude observations of targets within 62.5 degrees of the Sun, limiting observations of certain Solar System objects (e.g., comets) and coordination with Solar System spacecraft observations that violate this constraint.

1.4.2 Gyro pointing control prohibited
Observations on gyro pointing (i.e. DROP TO GYRO) are not permitted. This precludes the use of “DASH” mode and also observations of the Moon.

1.4.3 Moving target and spatial scan rates limited
Moving target and spatial scan observations at rates exceeding 5 arcseconds per second are not supported. This precludes moving targets within roughly the orbit of Mars and WFC3/IR grism observations of targets brighter than H_ab <~4.

Furthermore, serpentine scans are restricted to < 1 arcsecond per second.

1.4.4 Guide star handoffs prohibited
Fast moving targets may require visits which exceed the range of the FGS requiring switching to different guide stars. This is rarely used and is not available in RGM.
1.4.5 Multiple acquisitions in a single orbit are prohibited
Observations are restricted to a single guide star acquisition per orbit and thus observations at different orientations within an orbit are precluded. This constrains roll angle deconvolution strategies.

1.4.6 Orientation (roll) limits
Additional constraints on off-nominal roll angles are required and are dependent upon the orbit of HST and the position of the target. These may produce additional scheduling restrictions for a given observation.

1.5 Scheduling efficiency consequences
Based upon experience in 2007-2009, RGM will impact the overall scheduling efficiency of HST resulting in fewer scheduled orbits per year. The long-term average with three gyros is approximately 84 orbits per week (plus snaps). This is expected to decline to ~73 orbits per week in RGM hence a decrease of~500-600 orbits per year of scheduled primary science and external calibration observations. These numbers depend upon the mix of science observations (e.g. the increased frequency of long exoplanet transit visits or disruptive targets of opportunity observations does decrease the number of schedulable orbits somewhat but represent high priority science) and are estimates.

In 2007-2009, RGM also reduced the time available for science observations within an orbit by 2-4 minutes (i.e., overheads necessary for target acquisition were increased). The necessity of adjusting to various issues with HST’s pointing control systems over the past decade has already incorporated those reductions and further reductions (if any) are expected to be on the order of 1 minute or less.

Operation of HST using Gyro 3 has resulted in an increase in failed acquisitions due to the erratic behavior sometime present in that gyro. It is expected that the frequency of failed acquisitions will be lower in RGM than when using Gyro 3, but somewhat higher than was the situation in the past with 3 “quiet” gyros (i.e., prior to 2018).

Some observing programs likely will unavoidably need to be stretched over multiple years due to competition for more limited scheduling windows. These may include (but are not limited to) observations concentrated in certain regions of the sky in higher demand, observations requiring long separations between visits, observations requiring repeated use of the same roll angle.

Section 2: HST Pointing and Target Acquisition Methods and Capabilities
As is evident from Section 1, the RGM mainly impacts the target acquisition aspects of the HST pointing control system. This section provides a description of HST’s systems and explains their evolution over the mission.

2.1 The operation and evolution of the HST pointing control system (PCS)
When HST was originally designed, its available flight computers were very limited, yet the observatory was required to provide both pointing stability to better than 7 milli-arc seconds (mas) and to perform offset observations to comparable precision. This demanding set of requirements (especially in the early 1980s) was met by a combination of interferometric field guidance sensors, high precision gyroscopes, star trackers, and a then capable DF-224 computer (also responsible for many other flight operations). The gyros retained sufficient knowledge of HST’s attitude during Earth occultation (HST slews very
slowly and therefore accepts beings blocked by Earth for ~30-40% of each 96 minute orbit) to enable re-acquisition of guide stars each orbit, or finding new guide stars after a slew to a new target. While the star trackers provide some update capability, as shown below they have important limitations so the gyros are the primary source of spacecraft attitude knowledge.

Once that telescope is pointed within about one arc minute of its target guide stars, the FGS are able to located the pre-selected guide stars. Once the telescope is precisely pointed on the desired target (by moving the FGS internal optics to the desired locations), the science observation may commence. To obtain the required pointing stability, the gyros provided 40 Hz attitude updates and the FGS corrected gyro drifts at a 1 Hz rate due to the limited capacity of the DF-224 flight computer.

Fortunately, the DF-224 computer was replaced in 1999 during Servicing Mission 3a with a far more capable unit developed at GSFC using Intel 486 micro-processors. This has enabled RGM by permitting the FGS drift signal to be processed by the 486 at 40 Hz to achieve pointing control better than 7 mas without the gyros in the control loop during the science observations (although one gyro is used to support roll control). Hence the gyros are now necessary only for target acquisition but not science guiding. After Servicing Mission 4 in 2009, six new gyros were installed and science observations were conducted using gyros in the PCS during science guiding with jitter performance only slightly better than RGM.

After the failure of three of the six gyros, it was found that one of the remaining gyros (Gyro 3) was somewhat noisy and unstable, resulting in both a higher frequency of failed target acquisitions and dropped guide stars during science observations. The latter was remedied by the development of the “hybrid” mode (Hybrid 3G-F1G) discussed above, using three gyros during target observations but only one gyro plus the FGS during science observations. This has been in place since 2021.

Full transition to RGM will be necessary when the performance of one of the remaining three gyros deteriorates sufficiently that science productivity is better despite the limitations discussed in Section 1.

2.2 RGM operations

RGM was developed in 2007 due to gyro failures subsequent to Servicing Mission 3b in 2002. The RGM approach uses the FGS plus 486 computer for science guiding (as discussed in 2.2) combined with a more complex strategy for target acquisition. With only one or two working gyroscopes, HST’s attitude will drift many degrees during Earth occultation and the gyros will be unable to provide sufficient input to the PCS to position HST such that the FGS can acquire guide stars (a ~1 arc minute requirement). This can be accomplished, however, with one of the fixed head star trackers (FHST).
The design of HST for operations in low Earth orbit comes with many constraints. One critical set of constraints limit the spacecraft attitude relative to the Sun. One side (see Figure 2) is exposed to sunlight while the telescope aperture and the other side never see direct sunlight. Keeping sunlight out of the telescope aperture (to avoid a solar furnace) drives the 50 degree solar avoidance angle (62.5 in RGM due in part to drift during earth occultation). The need for thermal control of WFC3 protects its radiator (see Figure 3) from direct sunlight enabling the IR channel. Below WFC3 are located the three FHST. These units also may not directly view the sun. The upper one is pointed orthogonally to the telescope’s line of sight and the other two at an angle looking aft that avoids sun entering their apertures with taking science observations at the anti-sun (supporting a key requirement to observe Solar System objects at opposition).
The consequence of this geometry is that the field of view of the FHST only sees the sky during part of the orbit (it is otherwise blocked by the earth). Since the FHST must be used in RGM for attitude knowledge sufficient to acquire guide stars, observations are constrained to start when the FHST is not occulted by Earth. This is the primary contributor to the reduced field of regard in RGM.

Figure 3: Shadowed side of HST (never exposed to direct sunlight). From top of this image are the battery louvers/radiators, WFC3 radiators, and the FHSTs (black circle/ovals). The NICMOS Cooling System radiator is the white panel to lower right.