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NIRSpec Performance Report

NPR-2013-002 / ESA-JWST-RP-19654

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Date of Issue: 20.5.2013
Version: 1

NIRSpec Operational Efficiency

Abstract:

This report summarizes the current understanding of NIRSpec operational overheads, and provides an estimate for the in-orbit operational efficiency. Assuming a realistic mission scenario (i.e., a predicted distribution of visit lengths), the NIRSpec efficiency is shown to meet its requirement with margin. In addition, it is shown that the duration of the NIRSpec target acquisition procedure marginally violates the requirement.

1 INTRODUCTION AND SCOPE

This document serves to demonstrate that NIRSpec can meet its required operational in-orbit efficiency. The governing document is RD1, the NIRSpec Functional Requirements Document (FRD). It contains two requirements that address the operational efficiency:

NSFR-18 *The operational efficiency of NIRSpec shall be at least 85 %.*
NSFR-38 *Target acquisition for a new target field shall be accomplished within 10 minutes.*

The corresponding requirement and explanatory note in RD2, the NIRSpec System Requirements Document (SRD), read as follows:

R 210: *The amount of time lost for instrument set-up and internal calibration shall be limited to 15 % or less of the allocated NIRspec observing time, calculated as an average over the nominal mission duration.*
D: *This overhead includes activities such as the full target acquisition procedure, moves of the filter and grating wheel, configuration of the MSA, measuring the position of the imaging mirror on the grating wheel (if required), and any necessary exposures using the internal calibration source. It does not include telescope slews and other observatory related operations.*

Section 2 of this document describes the JWST guidelines for calculating the overhead rates. The NIRSpec internal overhead times for activities such as mechanism movements, exposure configuration, calibration lamp switch-on, etc., are outlined in Section 3. Part of the NIRSpec mission overhead are the in-orbit calibration activities which are summarized in Section 4. Using an assumed "typical" science visit scenario described in Section 5, one can derive the expected duration of the target acquisition sequence, as well as the total overhead time per NIRSpec science visit (Section 6). This allows one to calculate the resulting in-orbit operational efficiency by comparing the average visit duration to the time that is "lost" to internal overheads. Note that the average visit length depends sensitively on the type of science proposals that NIRSpec will execute. Because the JWST science program is still unknown, we use an agreed mission scenario (described in Section 7) that balances the relative fraction of short, medium, and long NIRSpec visits.

1.1 Reference Documents

Table 1-1 List of reference documents

ID	Title	Document #
RD 1	NIRSpec Functional Requirements Document	JWST-RQMT-002060
RD 2	NIRSpec System Requirements Document	ESA-JWST-RQ-322
RD 3	NIRSpec Operations Concept Document	ESA-JWST-TN-0297
RD 4	Observation Efficiency Allocations Report	JWST-REP-004166
RD 5	NIRSpec Inputs to Scripts for FM Cryo Campaign	NIRS-ASD-TN-0189
RD 6	Calibration of the GWA position sensors – Part II	ESA-JWST-RP-19657
RD 7	Calibration of the GWA position sensors – Part III	ESA-JWST-RP-19656

2 GUIDELINES FOR COMPUTING OVERHEADS

The guidelines for computing overhead times for the JWST observatory and its science instruments have been outlined in Table 3-1 of the "Observation Efficiency Allocations Report" (RD4). This table allocates the different type of overhead activities to specific elements of the mission. More specifically, the following activities must be included in the overhead computation of the science instruments:

i) internal lamp calibrations
ii) overheads associated with setting up and reading out the SI detectors
iii) any setup and/or cleanup activities
iv) all mechanism movements
v) all target acquisition activities

Activities that are **not** to be included when estimating SI overheads are the large-scale telescope slews and any small-angle maneuvers (SAMs), except when needed for target acquisition. Also explicitly excluded are all external calibration exposures, e.g. sky flats or observations of spectro-photometric standard stars or astrometric reference fields.

3 NIRSPEC OPERATIONAL OVERHEADS

The duration of all activities required to configure the NIRSpec instrument for science exposures are listed in Table 3-1. These overheads, which are detailed in RD 5, have been measured by EADS during the cryogenic test campaign in January 2013.

Table 3-1 NIRSpec overheads as measured during ground testing (from RD 5)

RMA	- move to REF position - move by n motor steps to specific position	< 270 s 14s + (n/60)s
FWA	- move by 1 position - move by 2 positions - move by 3 positions - move by 4 positions	27s 39s 51s 63s
GWA	- move by 1 position - move by 2 positions - move by 3 positions - move by 4 positions	27s 39s 51s 63s
CAA	- Power on - specific lamp switch on - lamp switch off	5s 17s 10s
DS	- toggle between SUBARRAY/FULL and STRIPE mode - Exposure set-up - Exposure clean-up	60s 16s to 22s 5s to 8s
MSS	- configure to "all open" or "all closed" - block/unblock IFU aperture - configure specific MSA pattern	60s 75s 90s

For the purpose of this study, we make the following conservative assumptions:

- a wheel mechanism movement will always turn the mechanism by two positions, i.e. the duration of every movement of FWA or GWA is assumed to be 39s. This is conservative, because careful planning of the observation sequence can - in most cases - result in having to move the wheels by only one position.

- whenever the MSA is configured, we assume that it is configured to a specific MSA pattern, even when this pattern is "all open" or "all closed". In other words, we always assume 90s for an MSA configuration, even though it may in many cases be possible to use pre-programmed configurations which would reduce the overhead.

- for the detector system configuration, we always assume the maximum duration of 30s.

4 IN ORBIT CALIBRATION ACTIVITIES

Throughout the lifetime of JWST, the calibration of its science instruments will be maintained via an in-orbit calibration monitoring program. As described in Section 2, only the parts that use internal lamp illumination are counted as SI overhead. In the case of NIRSpec, the main internal calibration program is the "spectral flatfield and wavelength calibration" that must be executed regularly for both the integral field unit (IFU) and the micro-shutter array (MSA).

Both programs involve lamp illumination of the respective aperture (IFU or a long-slit pattern in the MSA) using all seven NIRSpec dispersers (6 gratings and 1 prism). Both test sequences (MON-COMBO-MOS and MON-COMBO-IFU) have been extensively used during the NIRSpec-level calibration campaigns. They will also be used for verification and monitoring purposes during the upcoming ISIM- and observatory-level test campaigns. Their duration is therefore well understood: 4.25 hrs for for each installment of MON-COMBO-IFU, and 1.75 hrs per MON-COMBO-MOS run.

Assuming (rather conservatively) that both programs need to be monitored twice a month, this would add a total of 12 hrs per month, or **144 hrs per year**, to the NIRSpec overhead.

5 SCIENCE VISIT SCENARIO

In order to estimate the total amount of NIRSpec overhead, one needs to make assumptions on the sequence of activities during a typical NIRSpec science visit. In this section, we describe these assumptions. The notion of a "typical" science visit implies that the sequence of events between subsequent Target Acquisitions (TAs) is always the same: the TA is followed by a series of science exposures taken in a dither pattern (see below) and through different gratings. The end of the sequence is marked by a final “clean-up” which puts the filter wheel in the closed position and the MSA to “all closed”.

5.1 Target Acquisition

The general procedure and event sequence for a NIRSpec TA is described in Section 6 of RD3. We assume that the starting conditions are as follows: FWA in OPAQUE, GWA in an arbitrary position, and the MSA in “all closed”. We use the “best case” TA procedure which does not require illumination of the fixed apertures via the CAA lamps in order to measure the exact position of the imaging mirror in the GWA. Instead, the procedure relies on the telemetry of the GWA tilt sensors that can be used to accurately correct for the small, but nevertheless important, non-repeatability of the GWA positioning. This approach has recently been validated based on analysis of NIRSpec cryogenic test data (RD 7).

We will further assume that the observer always needs to protect against bright stars in the field of view, so that a full MSA magnet sweep (up and down) is required to obtain the TA image. This again is somewhat conservative, because for fields without bright stars, the MSA magnet can, in principle, be left in the “up” position for the acquisition images, and the "down" sweep can be directly used to obtain the science configuration, thus saving a full magnet cycle. At the end of the TA sequence, after the corrective telescope SAM has been executed, an optional confirmation image through the science filter may be obtained. However, this image is not considered part of the TA sequence proper. Instead, if such a confirmation image is requested by the user, it is charged to the following science visit.

5.2 Science sequence

For simplicity, we assume that all NIRSpec observations – regardless of whether they are “short”, “medium”, or “long” - are identical in the sense that the observer wants to study the science object(s) over the full NIRSpec wavelength range. This implies that following a successful target acquisition, a spectrum is taken in each of the three NIRSpec bands.

Moreover, we assume that the position sensors on the GWA are sufficiently accurate that dedicated wavelength calibration exposures are **not** required after a GWA move. This assumption has been validated recently by the analysis presented in RD 6.

5.3 Visit Clean-up

We assume that at the end of each science visit, the MSA will be returned to its “all closed” state in order to protect the NIRSpec detectors during the subsequent telescope slews, and – more importantly – to minimize the “hold open” times for the MSA shutters in case of prolonged NIRSpec inactivity after the visit is completed. On the other hand, many NIRSpec visits may be continued by directly configuring the MSA to the TA configuration, in preparation for the following visit or science sequence, without going to “all closed” first. However, for simplicity and to remain conservative, we plan for the cleanup to be added to the end of each NIRSpec visit. Table 5-1 then summarizes the expected number of mechanism cycles for the "typical" NIRSpec science visit described above, as a function of the parameter *n* which denotes the number of dither positions, as described in the next paragraph.

Table 5-1 Mechanism usage per NIRSpec visit. The parameter *n* denotes the number of dither positions in a typical NIRSpec visit.

Type of activity	Small-Angle Maneuvers (SAMs)	FW moves	GW moves	DS Exposure Configuration	MSA magnet sweeps (up-down)	CAA cycles per lamp (on-off)	
						Cont.	Line
Target Acquisition	2	2	1	2	1	-	-
Science sequence (baseline)	n-1	3 × n	3 × n	3 x n	n	-	-
Science sequence (worst case)	n-1	5 × n	3 × n	6 x n	n	-	n
Clean up	-	1	-	-	1	-	-
Total (baseline)	n+1	3(n+1)	3n + 1	3(n + 1)	n+2	1	-
Total (worst case)	n+1	5n+3	3n + 1	6n + 3	n+2	1	n

5.4 Dithering Strategy

In order to improve the correction of small-scale, pixel-to-pixel response variations of the detector, one should ideally move the entire set of NIRSpec spectra to a few different positions on the detector array, in what is commonly called a "dither pattern". Unfortunately, dithering is costly in terms of efficiency and lifetime considerations because it requires a new MSA configuration for each dither position, and possibly even a new TA procedure if the slew amplitude is too large to guarantee sufficient accuracy.

The most efficient way of completing a dither pattern while covering the entire NIRSpec spectral range is to cycle through all NIRSpec gratings at a given dither position. This minimizes the number of telescope slews and MSA configurations. On the other hand, it increases the number of movements for both wheel mechanisms by a factor equal to the number of positions in a dither pattern.

The number of dither positions is therefore an important parameter for estimates of the mechanism usage. Unfortunately, it is also very difficult to predict because it depends critically on the detector performance and the science requirements of the given observation. While Table 5-1 includes a free parameter *n* to describe the number of dither positions, the remainder of this note will assume a value of *n*=2 which allows us to cover the spectral gap caused by the physical distance between the two FPAs.

6 OVERHEADS PER SCIENCE VISIT

6.1 Duration of Target Acquisition Sequence

Using Table 5-1, and the overhead times listed in Table 3-1, the total duration of the target acquisition activity can be estimated as follows:

2 x 60 s for SAMs (allocation, consistent with MR-179)
+ 2 x 60 s for 2 external TA exposures (3 full-frame reads + overheads)
+ 2 x 60 s for on-board processing of the 2 TA images
(allocation, includes centroiding, averaging, slew computation etc.)
+ 1 x 39 s for GWA
+ 1 x 39 s for FWA
+ 2 x 30 s for exposure setup
+ 1 x 90 s for MSA configurations
================
~ 10.0 min per TA

Here, we have not accounted for the (optional) confirmation image that is obtained through the science filter at the end of the TA sequence as described in RD 3. This implies that the FWA remains in the TA filter position when the science activities start. This is fair, because the confirmation image is optional and, if desired, should be charged to the duration of the science visit.

The total TA duration therefore is compliant with requirement NSFR-38, albeit with no margin.

6.2 Total overhead per visit

Using a value of n=2 with the "baseline scenario" in Table 5-1 allows one to calculate the total overhead time per science visit as follows:

600 s for TA (see Section 6.1)
+ 8 x 39 s for GWA
+ 5 x 39 s for FWA
+ 6 x 30 s for exposure setup
+ 3 x 90 s for MSA configurations
================
~ 26.0 min overhead per science visit (with 1 TA)

In order to estimate what percentage of NIRSpec science time this fixed amount of overhead corresponds to, the next section describes the assumed distribution of NIRSpec science visits.

7 MISSION SCENARIO

The assumed mission scenario for JWST and NIRSpec is a crucial ingredient in estimating the efficiency of the observatory in general, and its science instruments in particular. The scenario described in this section is identical to what has been used to estimate the observatory efficiency (RD4) and the NIRSpec mechanism lifetime usage (RD3).

The design lifetime of JWST is 5 years after commissioning. The observatory is designed to be available for science observing 90% of those 5 years, i.e. all activities related to observatory and telescope maintenance such as angular momentum management, re-phasing of the primary mirror, and slews to a new target field will not occupy more than 10% of the time. We assume here that NIRSpec is the primary instrument 1/3 of the available science time, i.e. roughly 10^7 seconds per year.

Table 7-1 lists the assumed distribution for the various types of NIRSpec science visits, i.e. short, medium and long. The last column in **Table 7-1** lists the likely number of TA sequences associated with each of these visits. We assume that NIRSpec will have to execute a single TA sequence for visits shorter than 10,000 s, and – crucially - that no additional TA sequence is required after executing the dither maneuver. Should this assumption prove to be wrong, the total overhead calculated in Section 6.1 simply needs to be doubled because the entire sequence has to be identically repeated within the same visit.

For visits longer than 10,000s, thermally induced drifts in the ISIM structure, as well as the need to re-point the high-gain antenna for data downlink, can lead to changes in the relative alignment between the Fine Guidance Sensor (FGS) and NIRSpec. Such drifts would, of course, invalidate the alignment of the NIRSpec targets within their shutter (or slit) apertures, and another TA procedure is therefore likely to be necessary.

Table 7-1 Observation types

Type of Observation	Fraction of NIRSpec Time	Time per visit [s]	Number of Visits / year	Number of TAs / visit	Number of TAs / year
Short	10%	5,000	200	2	400
Medium	60%	20,000	300	2	600
Long	30%	100,000	30	10	300
Total	100%	1.0×10^7	530	-	1300

The NIRSpec mission scenario outlined in **Table 7-1** implies that on average, **NIRSpec will be used for 530 visits per year**, with an average visit length of 10^7 s/530 ~ 314 min.

8 CONCLUSIONS

We have shown in Section 6.2 that the fixed NIRSpec overhead per science visit is 26.0 min. In addition, NIRSpec requires at most 144 hrs per year for internal calibration activities (see Section 4). By using the "typical" visit scenario described in Section 5, and a reasonable distribution of visit types that amounts to 530 NIRSpec visits per year (Section 7), one arrives at the following total overhead budget per year of NIRSpec use:

$$((530 \text{ visits} * 26.0 \text{ min/visit}) + 144 \text{ hrs}) / 10^7 \text{ s} = 0.135$$

In other words, **the NIRSpec operational efficiency is ~ 86%**. Given that some of the assumptions that went into the calculation are rather conservative, the requirement of 85% is met with some margin.

Finally, the requirement for the duration of the NIRSpec TA procedure is also met, albeit with no margin except for some conservative assumptions on the duration of the relevant on-board computations.