VERT-X Design of Vertical X-Ray Test Facility for ATHENA

TN19 SCHEDULE ESTIMATE FOR THE MA QM/FM VERIFICATION AND CALIBRATION CAMPAIGN

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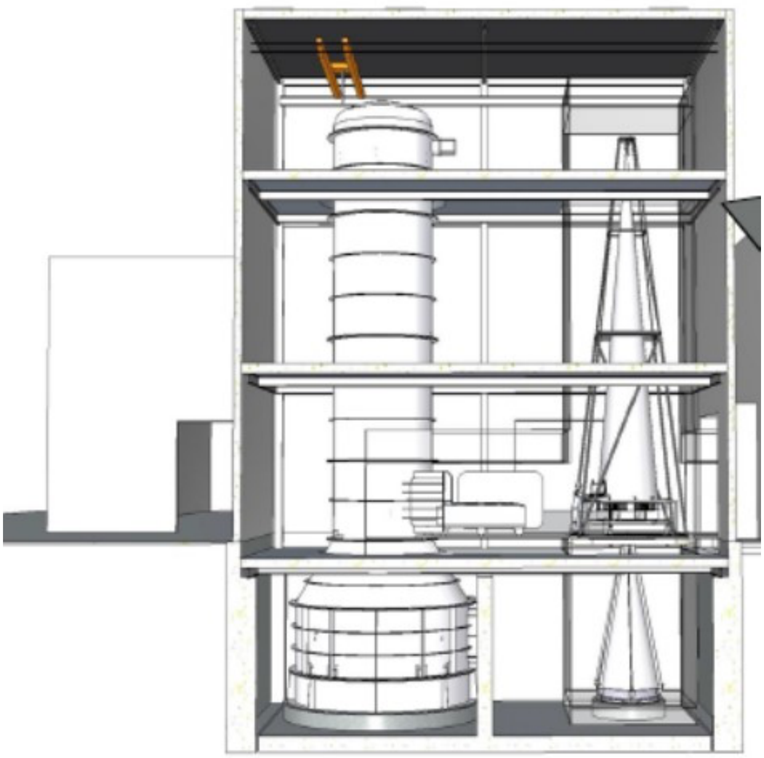

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1. INTRODUCTION

1.1. SCOPE

The scope of the present document is the illustration of the schedule estimate for the Mirror Assembly (MA) Qualification and Flight Model (QM/FM) verification and calibration activities in the VERT-X facilities, following the outcomes of the Detailed Design Review (DDR) and the study activities up to the Final Review (FR).

1.2. APPLICABILITY

The present document is one of the deliverables related to the FR milestone. It is intended to describe the schedule estimate for the MA QM/FM verification and calibration campaign in the VERT-X facility.

1.3. ROADMAP

Document section	Content description
Section 2 (Applicable and reference documents)	List of applicable documents and reference documents.
Section 3 (Overview)	Overview of verification and calibration campaigns in VERT-X facility.
Section 4 (Test durations)	Details of tests durations for HEW and effective area, optical axis, focal length and stray light.
Section 5 (MA FM verification campaign schedule)	Details of schedule estimate for MA FM verification campaign in the VERT-X facility.
Section 6 (VERT-X FM calibration campaign)	Details of schedule estimate for FM calibration campaign.

Table 1-1: Roadmap of the document

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1. APPLICABLE DOCUMENTS

AD1	AO/1-9549/18/NL/AR - SOW X-ray Raster Scan Facility for the ATHENA Mirror Assembly SOW
AD2	VERT-INAFOAB-001 VERTICAL X-Ray (VERT-X) Technical Proposal
AD3	ESA-TECMMO-RS-014713 Updated Requirements for the ATHENA VERT-X following the System Requirements Review
AD4	ATHENA - MCF URD, IRD & ICD ISSUE 1.3 [ESA].pdf
AD5	ATHENA - MCF URD, IRD & ICD WORKING DRAFT 04-06-2020
AD6	ATHENA - Calibration Requirements Document, ESA-ATH-SP-2016-001, issue 0.5.1.pdf
AD7	ATHENA - Optics Calibration Plan, ESA-ATHENA-ESTEC-SCI-PL-0001, Issue 1.1.pdf
AD8	
AD9	

2.2. REFERENCE DOCUMENTS

RD1	VTX-OAB-ISE-REP-003 D5 Detailed Design Document
RD2	VTX-OAB-IOP-TEC-001_i01p02_TN11Concept_of_Operation
RD3	VTX-OAB-ISE-TEC-001_i01p02_TN12_Technical_Budgets
RD4	VTX-OAB-ISE-TEC-002_i01p00_TN5_X-Ray_Detector_and_(xyz)_Stage
RD5	VTX-EIE-ISE-TEC-002_i02p00_TN3_Raster_Scan_System
RD6	

2.3. GENERAL SPECIFICATIONS AND STANDARD DOCUMENTS

SD1	ECSS-M-40A	Configuration management
SD2	ECSS-M-50A	Information/documentation management

2.4. LIST OF ACRONYMS

AD	Applicable Document
AIT	Assembly, Integration and Testing
DDR	Detailed Design Review
EA	Effective Area
EIE	European Industrial Engineering
ESA	European Space Agency
FM	Flight Model
FR	Final Review
GPAP	GP Advanced Projects
I/F	Interface
IASF	Istituto di AstroFisica Spaziale (INAF, Milano)
INAF	Istituto Nazionale di AstroFisica
ITT	Invitation To Tender
MA	Mirror Assembly
MLS	Media Lario S.r.l.
MM	Mirror Module
OAB	Osservatorio Astronomico di Brera (INAF, Milano)
PDR	Preliminary Design Review
QM	Qualification Model
RD	Reference Document
RS	Raster Scanner
SD	Standard Document
SOW	Statement of Work
SRR	System Requirements Review
TBA	To Be Assessed
TBC	To Be Controlled
TBD	To Be Defined
TEC	Technical Note
TVC	Thermal Vacuum Chamber
VERT-X	VERTICAL X-Ray
VTX	VERT-X
XRS	X-ray Raster Scanner
XSA	X-ray Source Assembly
XYZS	(x, y, z) stage

3. OVERVIEW

As specified in AD4 during the verification and calibration operations the following campaigns are planned:

1. Performance verification campaign tests for the MA QM (**3 months, start Apr 2025**);
2. Alignment checks during the MA FM integration campaign (**2 years, start Nov/2026**);
3. Performance verification campaign tests for the MA FM (**6 months, Sep/2028**);
4. FM calibration campaign (**6 months, Feb/2029**);

In AD4 two baselines are present: the first with the only XRCF NASA facility available, the second with both XRCF and VERT-X available for the ATHENA MA verification and calibration test purposes. According to this scheme VERT-X will be used only for the first part of the performance verification campaign tests for the MA QM, Alignment checks during the MA FM integration campaign and the first part of Performance verification campaign tests for the MA FM. Nevertheless, in the present document following the AD1 prescriptions we assume to perform the entire verification and calibration campaign in VERT-X.

PHASE	TEST	MM (TBC)	DATE (TBC)	DURATION (days)
(1) Mirror QM performance & EVT campaign	QM_AA	46	APR 2025	6
	QM_AFT	46	MAY 2025	4
	QM_AFT	46	MAY 2025	4
	QM_FULL	46	JUN 2025	4
(2) Mirror FM integration campaign	IAC_1	96	MAY 2027	6
	IAC_2	288	NOV 2027	6
	IAC_3	492	MAY 2028	7
(3) Mirror FM performance & EVT campaign	FM_AA	678	OTT 2028	7
	FM_AFT	678	NOV 2028	4
	FM_AFT	678	DEC 2028	4
	FM_FULL	678	JAN 2029	4
Calibration	CALIBRATION	678	FEB 2029	120

Table 3-1: Verification and calibration campaigns overview

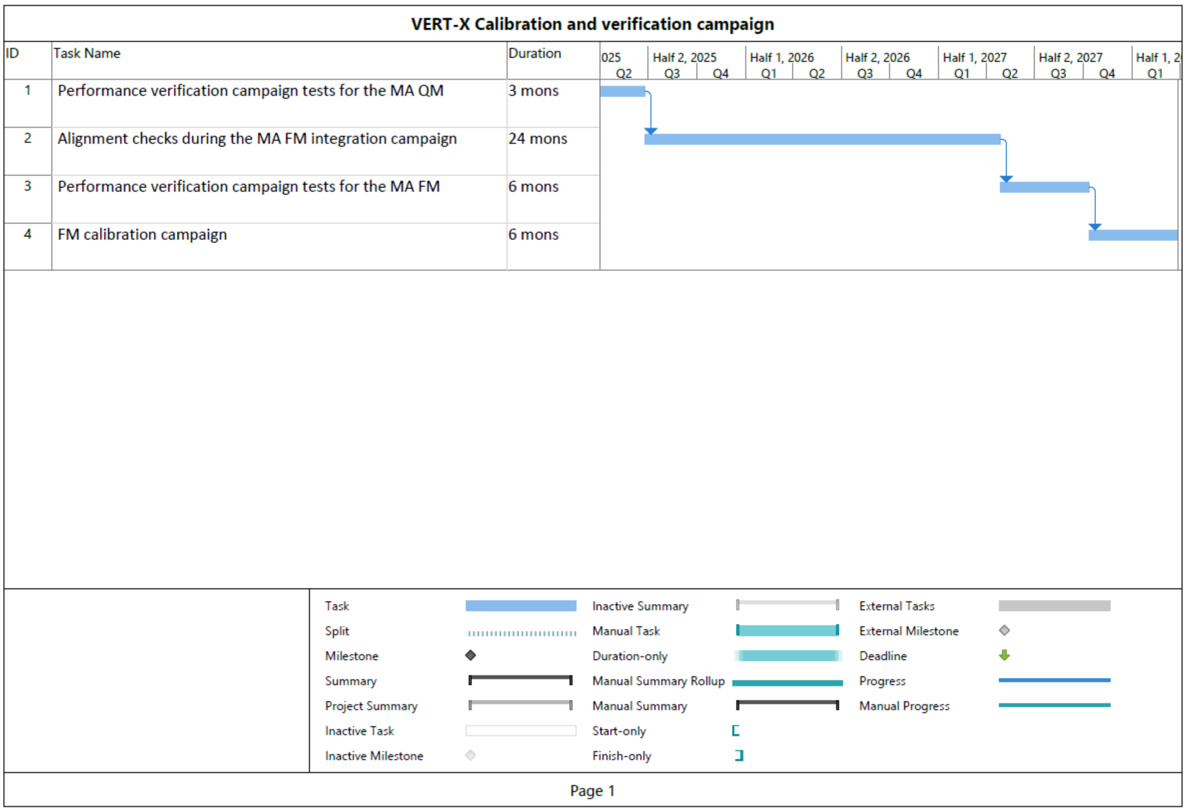


Figure 3-1: VERT-X calibration and verification campaign schedule

3.1. VERIFICATION TEST CAMPAIGN

Verification (points 1,2,3 of the previous table) will consist in different sequences of four tests, according the scheme defined in the Integration & Verification flows tab of AD5.

These four different tests are:

- Alignment acceptance (**AA**)
- Intermediate alignment acceptance (**IAC**);
- Abbreviated functional test (**AFT**);
- Full functional tests (**FULL**).

AA coincides with IAC, while FULL will perform the same tests of AFT at three energies instead of 1 energy with the MA TCS operating.

Scope and requirements of the four tests are the following.

<u>**AA** and **IAC** shall determine:</u>

- The MA optical axis; AKE ≤10" with 68% confidence.
- The MA on-axis A_{eff}; AKE ≤10% with 68% confidence.
- The MA focal length; AKE ≤100µm with 99.7% confidence at one energy (e.g. Al-K)

- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

At 3 energies (unless above otherwise specified, e.g.: C-K. Al-K, Ti-K), under a uniform temperature of 20°C ± TBD°C (thermal conditions mimicking the MM-->MA integration, and nominal flight operation), with the MA TCS not operating.

<u>**AFT** shall determine:</u>

- The MA on-axis A_{eff}; AKE of ≤10% with 68% confidence.
- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

At 1 energy, under a uniform temperature of 20°C ± TBD°C (thermal conditions mimicking the MM-->MA integration, and nominal flight operation), with the MA TCS not operating.

<u>**Full** shall determine:</u>

- The MA on-axis A_{eff}; AKE of ≤10% with68% confidence.
- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

At 3 energies (e.g.: C-K, Al-K, Ti-K), under TBD temperature conditions, with the MA TCS operating.

As said, the three verification campaigns will consist in several sequences of these 4 tests according the following scheme as defined in the Integration & Verification flows tab of RD3 (this is an initial specification of the performance verification requirements of the MA, and will be revised by the Primes):

1. Mirror QM performance: AA+AFT+AFT+FULL on the QM (1,8,15 rows, 2 sextans, 46 modules in total, TBC)
2. Mirror FM integration: three repetitions of IAC on FM with 1-3, 1-8, 1-12 integrated rows respectively
3. Mirror FM performance: Consists in the sequence: AA+AFT+AFT+FULL on the FM (15 rows, 6 sextans, 606 modules in total).

The list of the required measures during the verification phase are listed in Table 3-2.

WHERE	GOAL	ACCURACY	ENERGY	REQ	WHEN	WHAT
On Axis	FOCAL LENGTH	1mm (99.7%)	1 (Al-Kα)	LB-URD-365	AA, IAC	QM, FM1-3, FM1-8, FM1-12, FM.
On Axis	OPTICAL AXIS	10'' (68%)	3 (C,Al,Ti-Kα)	LB-URD-365-366	AA, IAC	QM, FM1-3, FM1-8, FM1-12, FM.
On Axis	HEW	2% (68%)	1 (C,Al,Ti-Kα)	LB-URD-368	AFT	QM, FM1-3, FM1-8, FM1-12, FM.
On Axis	A_{eff}	10% (68%)	1 (C,Al,Ti-Kα)	LB-URD-368	AFT	QM, FM1-3, FM1-8, FM1-12, FM.
On Axis	HEW	2% (68%)	3 (C,Al,Ti-Kα)	LB-URD-365-366-368-369	AA, IAC, FULL	QM, FM1-3, FM1-8, FM1-12, FM.
On Axis	A_{eff}	10% (68%)	3 (C,Al,Ti-Kα)	LB-URD-365-366- 368-369	AA, IAC, FULL	QM, FM1-3, FM1-8, FM1-12, FM.

Table 3-2: Summary of the Verification tests and corresponding required accuracy [RD3].

3.2. CALIBRATION TEST CAMPAIGN

Calibration consists in a 6-month test campaign starting in February 2029 (AD5). Goals and required accuracies are reported in AD6 and AD7 as summarized in RD2. While the calibration requirement on the HEW is not significantly different from verification, the main differences between verification and calibration are the following: (i) off-axis tests in 20 different positions; (ii) out of FOV test for the stray-light calibration purposes; (iii) required effective area calibration accuracy is significantly higher bot in absolute and relative terms.

In the following table we report a summary of the calibration requirements (RD2)

WHERE	GOAL	ACCURACY	ENERGY	REQ
ON Axis	Focal length	1mm (99.7%)	3(Al-Kα,Ti-Kα,Cu-Kα)	LB-URD-374 CAL-AST-R-002
On Axis	Optical axis	36" (99.7%)		LB-URD-373 CAL-AST-R-005
On Axis	HEW	0.1'' (68.3%)	7 (C-K / Ge-K)	LB-URD-376 CAL-PSF-R-001
On Axis	PSF	5% (68.3%)	7 (C-K / Ge-K)	LB-URD-376 CAL-PSF-R-001
Off-Axis	HEW	0.1'' (68.3%)	7 (C-K / Ge-K)	LB-URD-376 CAL-PSF-R-001
Off-Axis	PSF	15% (68.3%)	7 (C-K / Ge-K)	LB-URD-376 CAL-PSF-R-001
On Axis	A_eff (abs)	6% (68.3%)	10 (TBD 0.2-12.0 keV)	LB-URD-379

				CAL-EEF_R-001
On Axis	A_eff (rel)	2% (68.3%)	0.2-12.0 keV continuum, step 1/3 spectral resolution	CAL-EEF_R-003
Off Axis	A_eff (rel)	3% (68.3%)	0.3-7.0 keV continuum, step 1/3 spectral resolution	LB-URD-382 CAL-EEF-R-004
OUT Fov	Stray-light	5% (99.7%)	2 (Al-Kα,Fe-Kα)	LB-URD-383 CAL-PSF-R-003
Out focus	HEW	0.5'' (99.7%)	Not specified	LB-URD-377

Table 3-3: Summary of the calibration requirements [RD3].

4. TEST DURATIONS

The key factors in estimating the VERT-X test durations are:

- the detector sustainable count rate (allowing <1% pile-up level, as required by AD6). As described in RD3 and RD4 the expected value is 40 count/s in the single pixel event assumption.
- the scan time, which is the time needed by the raster-scan to cover the entire MA. It is estimated in RD5. At the nominal velocity of 30 mm/s the scan time is 3429s, including 504s of overhead for acceleration and deceleration at the row extremities. This time can be reduced down to 1970 s, doubling the scan velocity for the purposes of the stray-light calibration.
- the detector dimensions, which affects only the stray-light calibration.

4.1. HEW AND EFFECTIVE AREA

As reported in RD2 and RD3 we plan to perform PSF and EA calibration by means of a set of photon-counting observations using the bremsstrahlung continuum and exploiting the detector energy resolution; collecting 50,000 / KeV would allow to meet both the EA and PSF calibration requirements. In the case of Bremsstrahlung continuum, the calculation of the necessary exposure time T_{EXP} is not straightforward. This is because photon distribution is not uniform over the required energy band. Simulations described in RD2 show that time needed to cover a limited energy range (e.g. 0.2-4.0) in 11000 s. interval.

Moreover, our simulations showed that the fastest way to accumulate the required photons all over the 0.2-12.0 keV range, is to split the test in 3 different energy bands, by means of 2 different high pass filters, obtained by thick Be windows.

This results in a total of T_{EXP} ~ 56,000 s, to cover the full 0.2-12.0 energy band, accounting also for ~22,500 s for the direct beam calibration (flat field) useful for the EA calibration.

Although the expected durations vary from filter to filter (2-5% variations), in the following we adopt for each filter an average $T_{EXP} := T_{FILTER}$ = 19000 s per each filter.

4.2. OPTICAL AXIS

Optical axis will be measured by maximizing the flux over a set of N~10 PSF observations separated by an angular distance of ~ 10” (TBC). Exposure time of these observations is T_{SCAN}.

Note that, when the MA is not fully populated, like in the QM case or during the integration phase tests, the T_{SCAN} linearly scales with the occupation fraction.

4.3. FOCAL LENGTH

MA focal length will be measured by maximizing the flux over a set of N~10 intra and extra focus observations. Exposure time of these observations is T_{SCAN}.

Note that, when the MA is not fully populated, like in the QM case or during the integration phase tests, the T_{SCAN} linearly scales with the occupation fraction.

4.4. STRAY-LIGHT

Since we expect that stray-light is an extended emission, covering at least 2 quadrants of the FOV, for each required position (out of the FOV), a 20'x10' (7 cm x 14 cm) area (at least) should be covered. Assuming a 6 cm x 6 cm detector.

$T_{EXP} = 4 \times T_{SCAN} = 9752 \text{ s} * (6 \text{ cm} / DET\_SIZE)^2$

If necessary, the exposure time of these observations can be reduced increasing the scan velocity up to 60 mm/s.

4.5. SUMMARY

Summarizing: the relevant time scales to estimate schedules for both calibration and verification are

$T_{SCAN} = 3429s$

$T_{FILTER} = 19000s$

5. VERT-X MA FM VERIFICATION CAMPAIGN SCHEDULE

5.1. ALIGNEMENT ACCEPTANCE

AA shall determine:

- The MA optical axis; AKE ≤10" with 68% confidence.
- The MA on-axis A_{eff}; AKE ≤10% with 68% confidence.
- The MA focal length; AKE ≤100µm with 99.7% confidence at one energy (e.g. Al-K)
- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

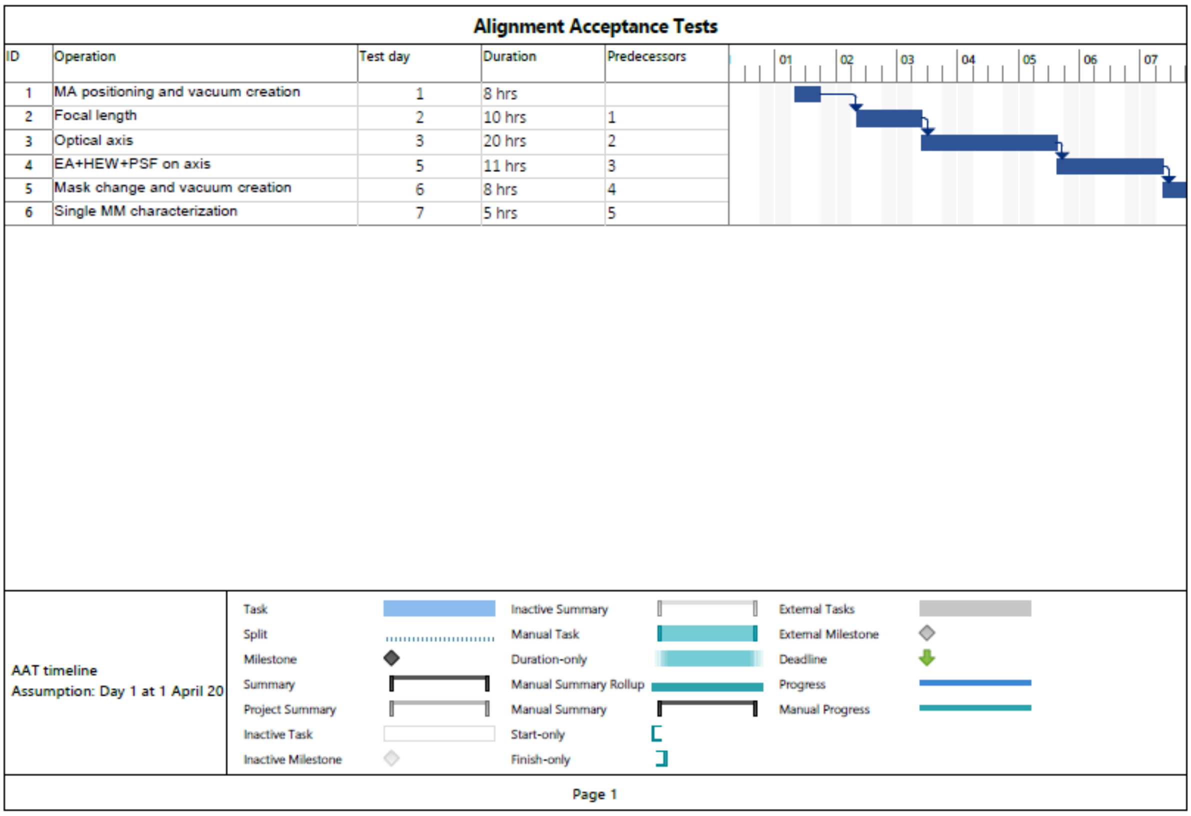
At 3 energies (e.g.: C-K. Al-K, Ti-K), under a uniform temperature of 20°C ± TBD°C (thermal conditions mimicking the MM-->MA integration, and nominal flight operation), with the MA TCS not operating.

We define E1:=C-K, E2:=Al-K and E3:Ti-K. For the purposes of the AA test and the following we assume to cover E1 and E2 with the same high-pass filter, while E3 will be covered in a second observation with the second high-pass filter.

In the following the schedule of the FM_AA; we estimated a shorter T_{SCAN} and 6 day duration for the case of QM_AA

OPERATION	Energies Required	N filter	N test	Exposure	Tot duration (hr)	schedule (day)
MA positioning and vacuum creation	-	-	-	-	8	1
Focal length	1	1	10	T_{SCAN}	10	2-3
Optical axis	3	2	10	T_{SCAN}	20	3-5
EA+HEW+PSF on axis	3	2	1	T_{FILTER}	11	5-6
Mask change and vacuum creation	-	-	-	-	8	6
Single MM characterization	1	1	1	T_{SCAN}* x 5	5	7

Table 5-1: Alignment acceptance tests preliminary schedule



Alignment Acceptance Tests

ID	Operation	Test day	Duration	Predecessors
1	MA positioning and vacuum creation	1	8 hrs	
2	Focal length	2	10 hrs	1
3	Optical axis	3	20 hrs	2
4	EA+HEW+PSF on axis	5	11 hrs	3
5	Mask change and vacuum creation	6	8 hrs	4
6	Single MM characterization	7	5 hrs	5

Figure 5-1: Alignment acceptance test preliminary schedule (for reference only)

5.2. ABBREVIATED FUNCTIONAL TEST

<u>**AFT** shall determine:</u>

- The MA on-axis A_{eff}; AKE of ≤10% with 68% confidence.
- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

At 1 energy, under a uniform temperature of 20°C ± TBD°C (thermal conditions mimicking the MM-->MA integration, and nominal flight operation), with the MA TCS not operating.

OPERATION:	Energies Required	N filter	N test	Exposure	Tot duration (hr)	schedule (day)
MA positioning and vacuum creation	-	-	-		8	1
EA+HEW+PSF on axis	1	1	1	T_{FILTER}	6	2
Mask change and vacuum creation	-	-	-	-	8	3
Single MM characterization	1	1	1	T_{SCAN} x 5	5	4

Table 5-2: Abbreviated functional tests preliminary schedule

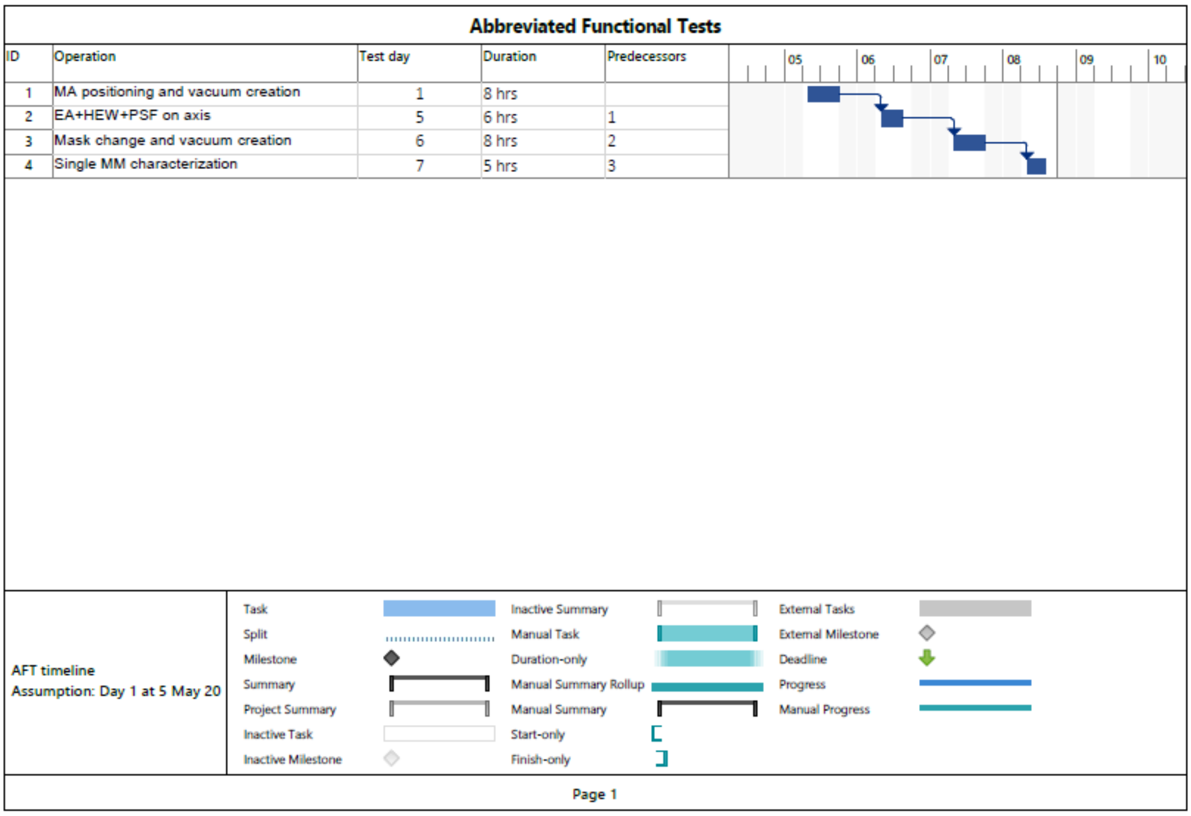


Figure 5-2: Abbreviated functional test preliminary schedule (for reference only)

5.3. INTERMEDIATE ALIGNEMENT ACCEPTANCE (= AA)

IAC shall determine:

- The MA optical axis; AKE ≤10" with 68% confidence.
- The MA on-axis A_{eff}; AKE ≤10% with 68% confidence.
- The MA focal length; AKE ≤100µm with 99.7% confidence at one energy (e.g. Al-K)
- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

At 3 energies (e.g.: C-K. Al-K, Ti-K), under a uniform temperature of 20°C ± TBD°C (thermal conditions mimicking the MM-->MA integration, and nominal flight operation), with the MA TCS not operating.

In the following the schedule of the IAC_3; we estimated a a shorter T_{SCAN} and a 6 day duration for the case of IAC_1 and IAC_2.

OPERATION	Energies Required	N filter	N test	Exposure	Tot duration (hr)	schedule (day)
MA positioning and vacuum creation	-	-	-	-	8	1
Focal length	1	1	10	T_{SCAN}	10	2-3
Optical axis	3	2	10	T_{SCAN}	20	3-5
EA+HEW+PSF on axis	3	2	1	T_{FILTER}	11	5-6
Mask change and vacuum creation	-	-	-	-	8	6
Single MM characterization	1	1	1	T_{SCAN} x 5	5	7

Table 5-3: Intermediate aligned acceptance tests preliminary schedule

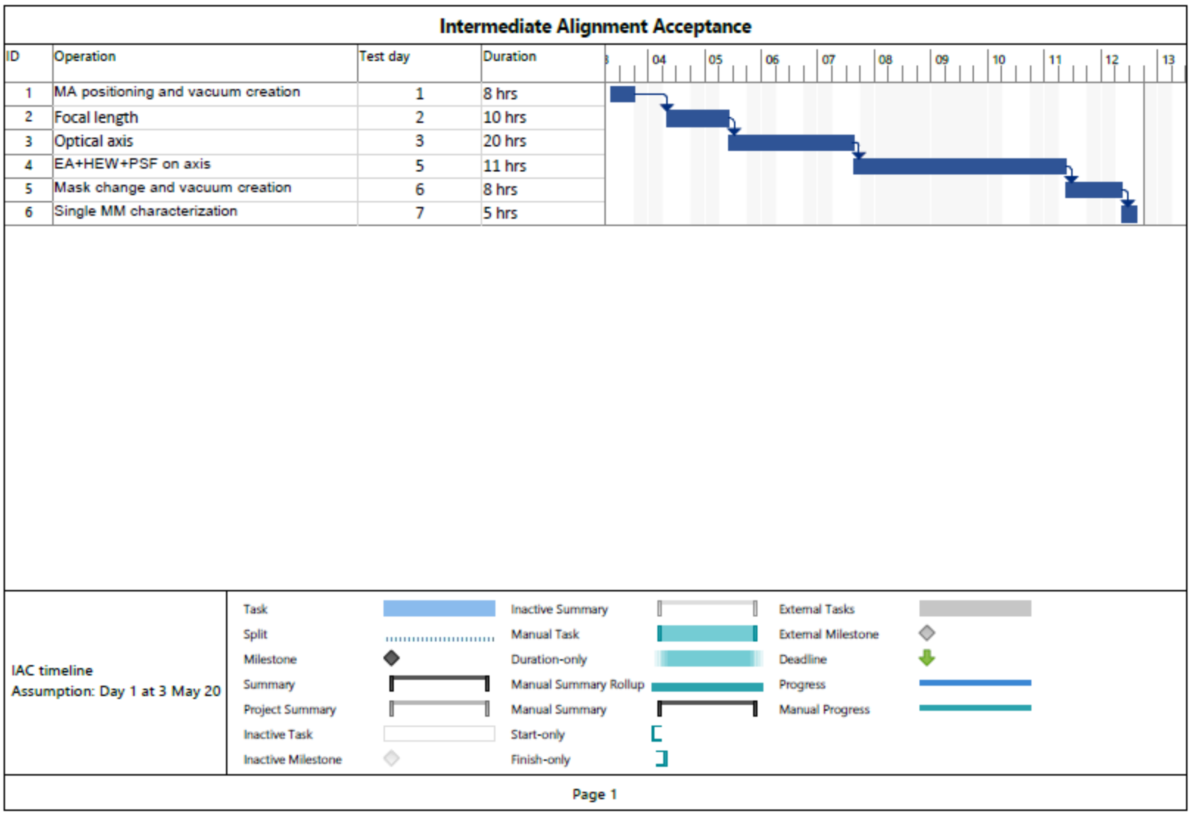


Figure 5-3: Intermediate aligned acceptance test preliminary schedule (for reference only)

5.4. FULL FUNCTIONAL TEST

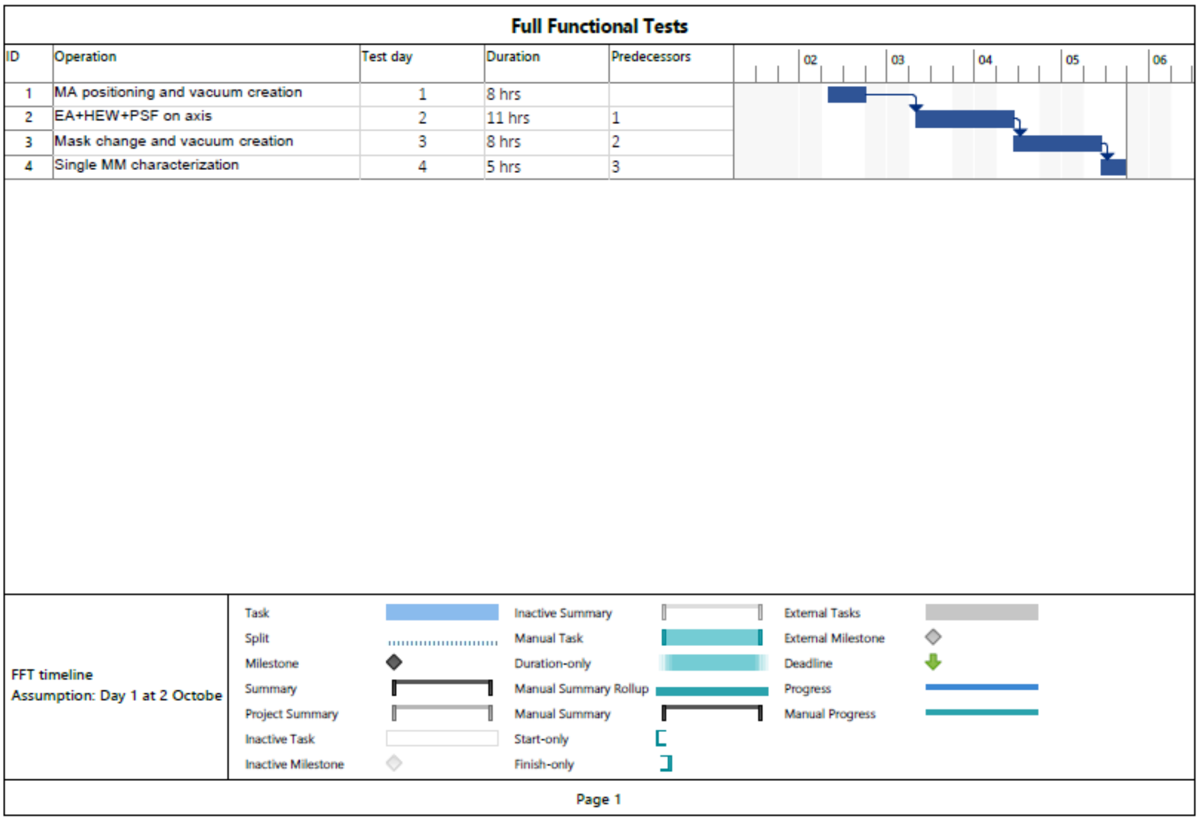
<u>**Full** shall determine:</u>

- The MA on-axis A_{eff}; AKE of ≤10% with 68% confidence.
- The MA on-axis PSF HEW; AKE of ≤2% with 68% confidence.

At 3 energies (e.g.: C-K, Al-K, Ti-K), under TBD temperature conditions, with the MA TCS operating.

OPERATION	Energies Required	N filter	N test	Exposure	Tot duration (hr)	schedule (day)
MA positioning and vacuum creation	-	-	-		8	1
EA+HEW+PSF on axis	3	2	1	T_{FILTER}	11	2-3
Mask change and vacuum creation	-	-	-	-	8	3
Single MM characterization	1 (TBC)	1	1	T_{SCAN} x 5	5	4

Table 5-4: Full functional tests preliminary schedule



Full Functional Tests

ID	Operation	Test day	Duration	Predecessors
1	MA positioning and vacuum creation	1	8 hrs	
2	EA+HEW+PSF on axis	2	11 hrs	1
3	Mask change and vacuum creation	3	8 hrs	2
4	Single MM characterization	4	5 hrs	3

Figure 5-4: Full functional test preliminary schedule (for reference only)

6. VERT-X FM CALIBRATION CAMPAIGN

OPERATION	Energies Required	N filter	N test	Exposure	Tot duration (hr)	schedule (day)
MA positioning and vacuum creation	-	-	-		8	1
Focal length	3	2	10	T_{SCAN}	20	2-4
Optical axis	3 (TBC)	2	10	T_{SCAN}	20	4-6
EA+HEW+PSF on axis	10	3	1	T_{FILTER}	16	7-8
EA+HEW+PSF off axis	10	3	20	T_{FILTER}	317	9-48
Stray-light	2	2	10	T_{SCAN} x 4	77	49-58
Out-of-focus HEW	1 (TBC)	1	10	T_{SCAN}	10	59-60
Mask change and vacuum creation	-	-	-	-	8	61
Single MM characterization	1 (TBC)	1	1	T_{SCAN} x 5	5	62

Table 6-1: VERT-X FM calibration campaign preliminary schedule

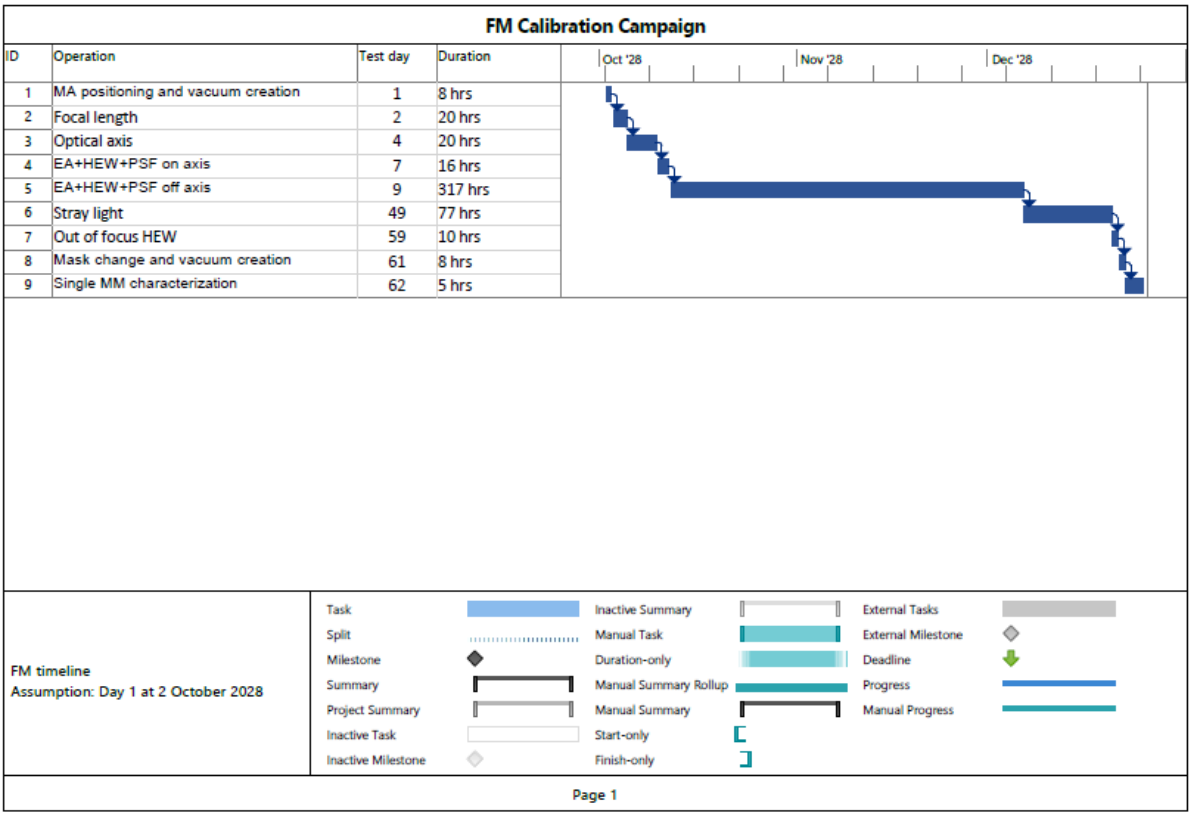


Figure 6-1: VERT-X FM calibration campaign preliminary schedule (for reference only)

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