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Final Report

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Contents

1.0 Purpose

This document defines the software developed by the SAO AXAF Mission Support (MS) Program and defines standards for the software development process and control of data products generated by the software.

2.0 Introduction

The SAO MS is tasked to develop and use software to perform a variety of functions in support of the AXAF mission. Software is developed by Software Engineers and Scientists, and Commercial Off-The-Shelf (COTS) software is used either directly or customized through the use of scripts to implement analysis procedures. Software controls real-time laboratory instruments, performs data archiving, displays data and generates model predictions. Much software is used in the analysis of data to generate data products that are required by the AXAF project, for example, on-orbit mirror performance predictions or detailed characterization of the mirror reflection performance with energy.

The challenge faced by the MS Software Team is to provide the appropriate level of formality to the software development process (documentation, testing, verification and validation) while not impeding the scientific process and remaining within budget. Software may be developed with a range of formality. The most formal approach to software development is formally proven software, a lower level might be DOD STD 2167B, then MM 1085.1, a Unit Development Folder approach, personally controlled software and finally no control (code comments only). In addition to the software process, the data products generated from the software need to be controlled such that the software version, documentation (algorithms etc.), input parameters and output data are linked and controlled. The control and traceability of software data products combined with the *appropriate* level of software development formality is the key to the effective management of a large body of non-deliverable software vital to the success of AXAF.

Our approach is to classify software according to the required formality of

the software development process, define a standard applicable to the most formal software and tailor the standard to the other classes.

3.0 Classification Schemes

In this section, we shall define the method by which software and data products are classified within SAO MS. In Sections 3.1 and 3.2, we describe the types of software and data generated and used by SAO MS. In Sections 3.3 and 3.4 we define four degrees of formal control and guidelines classifying software and data products. Finally, in Section 3.5, we define the actual software and data configuration items.

3.1 Functional Classification of MS Software

A wide variety of software is used by SAO MS and it is instructive to classify the software according to the function that it performs. According to function, SAO developed software may be divided into the following categories:

Deliverable GSE software: software controlling ground support equipment (GSE). This software is necessary for the proper functioning of GSE and therefore must be stringently controlled

Laboratory Control software: software controlling laboratory equipment. Insofar as this laboratory data is dependent on the proper functioning of this software, this software must be stringently controlled.

Analysis and Modeling software: software used in analyzing the results of measurements and resulting in predictions concerning the performance of the AXAF-I observatory. This software needs to be controlled to an extent commensurate with the mission impact of the predictions it makes.

Prototype software: software used to prototype new techniques in areas such as modeling, data analysis, and instrument control. This software is loosely controlled in keeping with its volatile nature.

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3.2 Descriptive Classification of MS Data Products

A wide variety of data products are used and generated by SAO MS. These data products may be classified by the following categories:

Reduced Laboratory Data: results of analysis and reduction of experimental laboratory data such as reflectivity curves and optical constants. This data is controlled to an extent commensurate with mission impact.

Reduced Simulation Data: results of analysis and reduction of data acquired by simulation and modeling such as studies based on ray tracing. This data is controlled to an extent commensurate with mission impact.

3.3 Levels of Control for Software

The degree of control used for SAO MS software is determined primarily by the direct and indirect impact the software has upon the AXAF mission. For SAO MS generated Software, four levels of control are defined as follows:

Level I SW: Deliverable SW. Level I SW will be controlled in the manner of Level II SW. Furthermore, Level I SW may have additional controls to bring it in conformance to its associated Data Requirement (DR).

Level II SW: Mission Support Controlled SW. Level II SW is used for software with major mission impact. Level II SW include software used for making predictions used for making critical mission decision and software used for performing critical mission tasks.

Level III SW: Personal control SW. Level III SW has only minor mission impact. Examples of Level III SW include software developed to perform preliminary calculations to test spacecraft requirements or software for initial reduction of laboratory data.

Level IV SW: No formal control required. Level IV SW has no immediate mission impact and is typically software generated for prototyping or for explorative calculations.

A detailed description of each level is given in Section 4

In addition to SAO MS generated software, SAO MS also uses the following types of software:

COTS and PD: Commercial Off the Shelf software and Public Domain software include compilers, editors, statistical analysis packages, hardware drivers, and other commonly available software. These packages have been verified by agencies external to SAO and through common use. COTS and PD software is not developed further by SAO and SAO typically imposes no formal controls.

4GL SW: Fourth Generation software is software used to integrate existing SW packages (e.g. COTS/PD SW, SAO developed SW, library routines such as IMSL, NAG, IDL math functions, SAOLIB). 4GL software of modest complexity is typically controlled as Level III software.

3.4 Levels of Control for Data Products

The degree of control used for SAO MS data products is determined primarily by the direct and indirect impact the data product has upon the AXAF mission. For SAO MS generated data products, four levels of control are defined as follows:

Level I Data: Program controlled data. Level I data is data with major mission impact that must be delivered to the AXAF program in a predetermined format. Level I data will be controlled in the manner of Level II data. Furthermore, Level I data may have additional controls to bring it in conformance to its associated Data Requirement (DR).

Level II Data: Mission Support Controlled data. Level II data is data with major mission impact. Level II data products are used for making mission critical decisions and incorporated in mission critical tasks.

Level III Data: Personal control data. Level III data has only minor mission impact. Examples of Level III data are results of analysis and

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reduction used in technical memoranda and reports which do not affect mission scope or critical mission requirements.

Level IV Data: No formal control required. Level IV Data has no immediate mission impact and is typically data gathered from exploratory or prototype calculations and measurements.

In addition to the above mentioned data products, SAO MS also uses **COTS and PD data**. COTS/PD data are published measurements and mathematical functions available commercially or are in the public domain. This data has been verified by agencies external to SAO and through common use. COTS/PD data is not developed further by SAO and SAO typically imposes no formal controls.

3.5 Configuration Items

Configuration identification of software is established via the SAO UDF which includes the following:

1. Requirements and design documentation.

2. User documentation.

3. Software testing results.

4. Complete computer source code.

5. Change log.

Configuration identification of data products is established via a Data Notebook which includes the following:

1. Mathematical specification of analysis and reduction algorithms and techniques.

2. Enumeration of software packages used and input parameters

3. Results of consistency tests

4. Raw data used.

4.0 Tailored standards

In Section 4, we present a matrix of how SAO MS tailors the degree of formal control of software and data products. In particular, the degree of configuration management, organizational management, documentation standards, and verification are presented.

4.1 Configuration Management Levels

The configuration items for software and data products (the UDF and Data Notebook, defined in Section 3.5) shall be controlled at varying levels of formality. In all cases above Level IV, version and revision control shall be maintained. This enables one to repeat a calculation or a measurement at a later date.

The levels of configuration management are defined as follows:

Level I: control by SAO AXAF Program Configuration Manager in conjunction with SAO MS Software Configuration Manager. In addition to individual control, SAO MS control, configuration control is maintained at the program level in accordance with the *SAO Configuration Management Plan* (SAO-HEAD-PLAN-93-034) as well as with any additional requirements imposed by DR.

Level II: control by SAO MS Software Configuration Manager. In addition to individual control, configuration is maintained in the SAO MS library and accessible by all members of SAO MS.

Level III: version control by individual scientist or engineer.

Level IV: no required control.

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4.2 Organizational Management

The organizational complexity in managing software development or data acquisition varies with the level of control. The levels of organization are defined as follows:

Level I: hierarchical management with teams of scientists and engineers. The organization of each team shall be tailored to the complexity of the project. This organization shall be documented to the extent required by DR.

Level II: hierarchical management with teams of scientists and engineers. The organization of each team shall be tailored to the complexity of the project.

Level III: managed by individual scientist or engineer.

Level IV: managed by individual scientist or engineer.

4.3 Technical Documentation

The detail and content of the technical documentation for software and data products shall be determined by the level of control. Documentation is typically made by means of the SAO Unit Development Folder (UDF) for software and SAO Data Notebook for data products. The levels of documentation are defined as follows:

Level I: SAO UDF for software and Data Notebook for data products. UDF and Notebook shall be maintained in the SAO MS library and accessible by all members of SAO MS. Any additional documentation required by DR shall be provided.

Level II: SAO UDF for software and Data Notebook for data products. UDF and Notebook shall be maintained in the SAO MS library and accessible by all members of SAO MS.

Level III: SAO UDF for software and Data Notebook for data products.

Level IV: no documentation requirements.

4.4 User Documentation Standards

The detail and content of user documentation for software and data products shall be determined by the level of control and the potential user base. SAO MS documentation is typically based upon the UNIX man page. The levels of user documentation are defined as follows:

Level I: documentation required at a level comparable to the UNIX man page. Any additional documentation required by DR shall be provided.

Level II: documentation required at a level comparable to the UNIX man page.

Level III: documentation required at a level comparable to the UNIX man page.

Level IV: no documentation requirements.

4.5 Methods of Verification and Validation

Depending on the nature of the software and data product, different methodologies for verification and validation (V&V) are appropriate. Here we extend a TRW classification of V&V methods (Rogson, 6th SSWG presentation, April 1993):

Direct Testing consists of comparing data products or software function with results known to be correct. Results may be known to be correct either by requirements definition or by mathematical tautology.

Comparison consists of two or more agencies applying independently developed algorithms and software to the same input data. If their results

agree, it may be presumed that each set of software, the algorithms involved, and the resulting data products are correct.

Consistency consists of using data derived from two or more separate tests and comparing results where the test results overlap. Inconsistent results indicate that either the test equipment or the programs involved are in error. Consistency indicates that the results are correct in the areas of overlap.

Common use consists of using software or data products that is used by a large audience on a common basis. The widespread use constitutes verification by agencies outside SAO MS. This type of verification is applicable to most COTS/PD software and data products.

Previous use consists of using software or data products which has been used extensively in the past by members of SAO MS or other agencies and has produced documented reliable results. Documented previous experience may constitute sufficient verification for SAO MS.

SAO MS requires that all software and data products above Level IV be verified and validated by one or more of the above methods. Validation of SAO MS software and data products will use **direct testing** whenever feasible. The precise V&V tests shall be determined on a case by case method and documented in the SAO UDF for software and the SAO Data Notebook for data products.

Appendix A: MS Software and Data Products

In this section, we list software and data products in use by SAO MS broken out by their entry in the SAO MS Work Breakdown Structure (WBS). The lists are not all inclusive, but instead, give a representative picture of software and data products at SAO MS.

A.1 WBS and Software

The following table gives a partial list of the names and classifications of
software packages used to support each SAO MS WBS task.

WBS Task	Function	SW Package	SW Class	Verif.
3.2.1 Optical System Performance	raytrace FEM metrology fits Visualization	OSAC, MIRROR ANSYS TRANSFIT IDL	COTS PD COTS PD Level II COTS PD	a,b,c,d a,b,c,d b,c b,c,d
3.2.2 X-ray System Performance	raytrace raytrace	OSAC, MIRROR fit_OSAC	COTS PD Level II	a,b,c,d a,b,c,d
3.2.3 HRMA Calibration	raytrace Visualization Spectral fits Database	OSAC, MIRROR IDL, IRAF fitHRMA RDB	COTS PD COTS PD Level II COTS PD	a,b,c,d b,c,d a,b b,c,d
4.4 HXDS SW	Database Visualization XDS control	RDB IDL, IRAF HXDSsw	COTS PD COTS PD Level I	b,c,d b,c,d b,c
6.1 Reflectivity Studies	Database Visualization lab control	RDB IDL, IRAF HXDSsw subset	COTS PD COTS PD Level II	b,c,d b,c,d b,c
6.2 Synchrotron Studies	Database Visualization lab control	RDB IDL XIXON	COTS PD COTS PD COTS PD	b,c,d b,c,d b,c,d
Verification key: *a) comparison, b) consistency, c) previous use, d) common use.*				

A.2 WBS and Data Products

The following table gives a partial list of the names and classifications of data
products being generated by each SAO MS WBS task.

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WBS Task	Data Product	Data Class	Verif.
3.2.1 Optical System Performance	HRMA FE model Cygnus xcheck	Level II Level II	a,b,c a,b,c,d
3.2.2 X-ray System Performance	tilt analysis vignetting analysis	Level III Level III	a,b a,b
3.2.3 HRMA Calibration	HXDS error budget	Level III	a,b
4.4 HXDS SW	VXDS timing model HXDS timing model	Level III Level III	a,b a,b,c
6.1 Reflectivity Studies	reflectivity model coating analysis	Level II Level II	a,b a,b
6.2 Synchrotron Studies	reflectivity model optical constants contamination study	Level II Level II Level III	a,b a,b a,b
Verification key: *a) comparison, b) consistency, c) previous use, d) common use.*			

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Appendix B: Acronym List

AXAF	Advanced X-ray Astrophysics Facility
COTS/PD	Commercial Off the Shelf / Public Domain
DR	Data Requirement
FEM	Finite Element Model
GSE	Ground System Equipment
HRMA	High Resolution Mirror Assembly
HXDS	HRMA X-ray Detection System
MS	Mission Support
SAO	Smithsonian Astrophysical Observatory
SSWG	Software Systems Working Group
UDF	Unit Development Folder
V&V	Verification and Validation
VETA	Verification Engineering Test Article
VXDS	VETA X-ray Detection System
WBS	Work Breakdown Structure
XDS	X-ray Detection System