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DOCUMENT

Comet 67P/Churyumov-Gerasimenko Shape Models EAICD - Annex A: ESA NAVCAM Shape Model

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1 INTRODUCTION

1.1 Purpose and scope

This is an Annex to document *Comet 67P/Churyumov-Gerasimenko Shape Models EAICD* covering the ESA NavCam Shape Model (1).

The purpose of this annex is to explain how the ESA NavCam Shape Model of comet 67P/Churyumov-Gerasimenko was generated and how to interpret it. This shape model was produced during the Rosetta mission by ESA, and more precisely by the Rosetta Mission Operations Centre (MOC) at ESOC.

There are other shape models of comet 67P/C-G generated by other institutions during the Rosetta mission, which are documented in their respective annexes.

This document has been prepared by the RSGS (Rosetta Science Ground Segment) Archiving Team with inputs from the Rosetta MOC.

(1) The parent or main EAICD to which this document is an annex to is not publicly available yet.

1.2 Intended Readership

Users of the 67P/Churyumov-Gerasimenko ESA NavCam shape model.

1.3 Acronyms

Acronym	Meaning
EAICD	Experiment to Archive Interface Control Document
ESA	European Space Agency
ESAC	European Space Astronomy Center
ESOC	European Space Operations Centre
MOC	Mission Operations Centre
MTP	Mid Term Plan
NASA	National Aerospace Agency
NavCam	Navigation Camera
OSIRIS	Optical, Spectroscopic, and Infrared Remote Imaging System
PDS	Planetary Data System
PSA	Planetary Science Archive
RMOC	Rosetta Mission Operations Centre
RSGS	Rosetta Science Ground Segment
VRML	Virtual Reality Modelling Language
VSTP	Very Short Term Plan

Table 1 Acronyms

1.4 Applicable and Reference Documents

Applicable Documents	
AD.1	Planetary Data System Preparation Workbook, February 1, 1995, Version 3.1, JPL, D-7669, Part1
AD.2	Planetary Data System Standards Reference, February 27, 2009, Version 3.8, JPL, D-7669, Part 2

Table 2 Applicable documents

Reference Documents	
RD.1	Rosetta-Osiris to Planetary Science Archive Interface Control Document, Version 3.e, RO-RIS-MPAE-ID-015 (can be found in any OSIRIS data set in the PSA archive).
RD.2	Rosetta-NavCam to Planetary Science Archive Interface Control Document, Version 4.0, O-SGS-IF-0001 (can be found in any NavCam data set in the PSA archive).
RD.3	Reference frames and mapping schemes of comet 67P, Franck Scholten et al. 24th Sept. 2015, Version 2.0 (provided in the data set)
RD.4	Rosetta/Mars Express/Venus Express Mission Control System (MCS) Data Delivery Interface Document (DDID), v 4.4, RO-ESC-IF-5003
RD.5	Rosetta PLID Annex A, Flight Dynamics Interfaces, v 1.8, 20th Sept 2013, RO-ESC-IF-5506
RD.6	Gaskell, 2008
RD.7	Optical measurements for attitude control and shape reconstruction at the Rosetta flyby of asteroid Lutetia, M. Lauer, S. Kielbassa, R. Pardo, ISSFD2012 paper,Pasadena, California, USA, 2012
RD.8	Surface Characterization and optical navigation at the Rosetta flyby of asteroid Lutetia, R. Pardo de Santayana, M. Lauer, P, Munoz, F. Castellini, ISSFD2014 paper, Laurel, Maryland, USA, 2014.
RD.9	Optical measurements for Rosetta navigation near the comet, R. Pardo de Santayana, M. Lauer, ISSFD2015 paper, Munich, Germany, 2015.

Table 3 Reference documents

1.5 Contact Names and Addresses

The ESA NavCam Shape Model was created by the Mission Operations Centre (MOC) at ESOC. It was then compiled, documented and archived by RSGS (Rosetta Science Ground Segment) archiving team at ESAC.

You can contact RSGS archiving team at:

ESAC
P.O. Box, 78 28691 Villanueva de la Cañada
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2 OVERVIEW OF INSTRUMENT DESIGN, DATA HANDLING PROCESS AND PRODUCT GENERATION

2.1 Overview of Instrument Design (NavCam)

The shape model described in this document was built using NavCam images.

The NavCam instrument is composed of two identical cameras installed in the Rosetta spacecraft. The description in this section applies to both cameras.

The NavCam instrument is a camera designed mainly for navigation purposes. It operates in the visible range, covering a 5 x 5 deg field of view and based on a CCD sensor. Table 4 summarizes its main characteristics. For further details please see document RD.1 which can be found in the PSA in any NavCam data set.

Parameter	Value	Comment
Mass CAM-OH	6.050 kg	Camera Optical Head
Mass CAM-EU	2.700 kg	Camera Electronic Unit
Mass CAM-BAF	1.408 kg	Camera Baffle
Total Mass	10.158 kg	
Total Power	16.8 W	
Field of View	$5° \times 5°$	
Sensor Type	CCD	CCD47-20 by e2v
Number of Pixels	1024×1024	
Focal Length	152.5 mm	
Pixel Size	13 μm	
Pixel Angular Size	17 arcsec	
Aperture	70 mm 30 mm	Non-Attenuated Modes Attenuated Mode
F/Number	f/2.2 f/5.1	Non-Attenuated Modes Attenuated Mode
Limit Magnitude	$M_v = 11$	Exposure time 5 s, SNR ≥ 5
Saturation Magnitude	$M_v = 1.6$ $M_v = 0.8$	Whole spectral range, G2 Class; exposure time = 10ms
Integration Time	10 ms 30 s	Minimum, Maximum
Bias error (1 σ)	0.2 pixels	$M_v = 11$, exposure time = 5 s, Defocused mode
NEA (1 σ)	0.1 pixels	$M_v = 11$, exposure time = 5 s, Defocused mode
Commanded Window Size	20×20 1024×1024	Minimum pixel array Maximum pixel array
CCD Operative Temp. Range	-50°C +50°C	Minimum Maximum
CCD Performance Temp. Range	-25°C 0°C	Minimum Maximum

Table 4 NavCam main specifications

2.2 Data Handling Process

The shape model described in this document is a 3-D digital representation of the surface of the comet obtained by processing the NavCam images.

The techniques and algorithms used to process the data and produce the shape model are extensively discussed in the following papers (in chronological order of publication):

1. [RD.7] *Optical measurements for attitude control and shape reconstruction at the Rosetta flyby of asteroid Lutetia* : This paper was published previous to the arrival to the commet and describes the algorithms used to produce the Lutetia asteroid shape model.
2. [RD.8] *Surface Characterization and optical navigation at the Rosetta flyby of asteroid Lutetia* : This document was also published previous to the arrival to the commet. It describes in great detail the algorithms, techniques and software used to obtain the shape models as well as the validation of he results. It uses Lutetia as a test case but the same technique and tools were used later on to obtain the comet shape model. Together with [RD.7] it is the best description on the shape model algorithms.
3. [RD.9] *Optical measurements for Rosetta navigation near the comet*. It describes the technique used to obtain the commet shape model. It is specific for the commet shape model but it is less detailed that the previous two papers.

For the convenience of the reader the technique is briefly summarised in the next subsections. For further details see the references above.

2.2.1 Rough shape from silhouettes

A rough shape was obtained using the silhouette of the comet as observed on the pictures acquired by Rosetta NavCam. This technique is called silhouette carving.

It consists of starting with a usually rounded bigger shape than the actual body, and then the illuminated limb of the object is used to define the actual shape model. Every part that falls out of the silhouette is then carved out.

The shape from silhouette is an essential part to determine a good first estimate of the shape model to be used in more advanced techniques.

2.2.2 Fine 3D maplets

In a second step small 3D high-resolution maps (maplets) were created centred on landmarks spread all around the body. The technique employed was stereophotoclinometry that consists of translating the grey levels of the image into slopes assuming or not photometric properties of the surface. For more details see [RD.6].

2.2.3 Fine shape model

As a final step the collection of maplets is assembled together into a fine shape model.

2.3 Data Validation

The shape model has been validated at ESOC for operational use and has undergone scientific peer review.

2.4 Image Measurement Period

This shape model has been built using NavCam images taken from August to November 2014. More precisely the start and end date of the measurements are:

Start: 2014-08-06T12:22:19.000
End: 2014-11-02T11:52:56.000

However most useful information came from Sept-Oct 2014 when Rosetta was close to the comet.

2.5 Shape Model Versions

There is one single version of the shape model using the source data described in section 2.4. It is however delivered in different formats and at low and high resolutions.

3 ARCHIVE FORMAT AND CONTENT

3.1 Products Location

You will find the ESA NavCam shape model in different formats in different directories. See section 3.3 for a listing and description of the available formats.

Note that:

- The directory name SPC_ESA denotes that the shape model was created by ESA using stereophotoclinometry
- MTP009 corresponds to the so-called Mid Term Plan 9 and makes reference to the operational period from which the images to make the shape model were obtained.
- For each format there is a high resolution version and a low resolution version. They are identified by the file name.

The following are the relevant directories:

Directory /DATA/TRIPLATE/SPC_ESA/MTP009

Contains the shape model in the following formats:
- ROS
- WRL
- OBJ

All the formats in the TRIPLATE directory are text based files with facets given by three points.

Directory DATA/SPICE_DSK/SPC_ESA/MTP009

Contains the shape model in the following format:
- SPICE DSK format

Directory /EXTRAS/

Contains the shape model in the following format:
- STL

The STL files are in the EXTRAS directory because are not an officially accepted PDS format, since the label file does not provide all the necessary information for reading the data. Nevertheless it is considered a useful format and it is therefore provided as an extra files for the convenience of the users.

3.2 Products Naming Convention

The ESA NavCam shape model product has the following name for products with **ROS format**:

CSHP_DV_047_xx_{LORES/HIRES}_yyyyy.ROS

Where:

- CSHP: Stands for Comet Shape Product
- DV: Corresponds to a planning cycle of type V, i.e. Very Short Term Plan (VSTP).
- 047: Refers to the VSTP cycle number 47 (from 2 to 5 Nov 2014).
- xx is an internal MOC version number (version of the planning cycle).
- LORES or HIRES: Indicates that it is a low or high resolution version.
- yyyyy is a file version number internal to RMOC (e.g 00085 or 00086).

- ROS: Indicates it is in ROS format which is the original format used at RMOC.

The yyyyy file version number is only present in the version with format ROS in order to preserve the original Rosetta Mission Operations Centre (RMOC) file name but it is removed for the other formats (file extensions) in order to meet the maximum length requirement imposed by PDS standard.

For all other formats the name is slightly different:

CSHP_DV_047_xx_{LORES/HIRES}_*FFF.EXT*

Where:

- CSHP: Stands for Comet Shape Product
- DV: Corresponds to a planning cycle of type V, i.e. Very Short Term Plan (VSTP)
- 047: Refers to the VSTP cycle number 47 (from 2 to 5 Nov 2014)
- xx is an internal MOC version number (version of the planning cycle).
- LORES or HIRES: Indicates that it is a low or high resolution version
- *FFF*: Three letters indicating the format of the file. These letters are the same as for the file extension.
- *EXT*: It is the file extension.

This name comes from the naming conventions used for many products originating from the RMOC. For traceability it has been decided to preserve the original RMOC name. The fact that the name is linked to the VSTP 47 does not mean that images used to generate the model were acquired during VSTP 47. It only means that this file was delivered by RMOC with a group of files delivered at VSTP 47.

3.3 Product File Format

The files within the data are present in the following formats:

- **ROS**: This is the original format produced by RMOC.
- **WRL**: Virtual Reality Modelling Language (VRML) format. Often used by browser plug-ins to display virtual reality environments.
- **STL** format
- **OBJ** format
- **DSK**: Digital Shape Kernel. It is a binary format to be used with SPICE software. The file extension is BDS

ROS, WRL and OBJ formats are ASCII (plain text) whereas DSK format is binary.

Each data product is stored in one data file accompanied by a label file with same base file name but an extension of .LBL. The label file contains metadata describing the product according to PDS standard.

The products are delivered in the format defined in [RD4].

The next subsections give an overview of the characteristics of the different formats.

3.3.1 ROS format

The data products are provided by RMOC in ROS format, with .ROS extension. The data is composed of 1 header followed by 2 tables. The header describes the content of the file, giving among other things the number of vertices and of facets.

The first table gives the vertices of the shape model. The vertices are given in an indexed list.

Example:

1 -2.38583353364460230 -0.94753058679926411 -0.3629040077651267

The line above is the first row of the vertices table. The first number gives the index of the vertex and the three last numbers are the coordinates (x,y,z) of the vertex in the Cheops Reference Frame.

The second table gives the facets of the shape model. The facets are triangular.
Example:

1 3 1 500067 500091

The above line shows the first row of the facet table. The first number is the facet index. The second value is the number of vertices in the facet, always three in this case. The 3 last numbers give the index of the vertex from the vertex table.

See [RD4] for more details. Also the file format is fully described in the corresponding PDS label file (file with the same name and LBL extension).

3.3.2 WRL format

The WRL format is often used by 3D viewers.

The basic content is the same as the ROS format; there is a vertex table followed by a facet table. The text around these tables differs as the file is written in VRML format.

The vertex table is composed of 3 number lines, which are the (x,y,z) coordinates of the vertex in the Cheops Reference Frame. Example:

-2.3858335364460230 -0.9475305867992641 -0.3629040077651267

The facet table is composed of 4 number rows - Example:

176562 706248 706246 -1

The first three numbers are the indices of the 3 vertices in the vertex table, counting from 0 – i.e. the first line of the vertex table is numbered "0".

The last number indicates the end of the list of vertices in the described face.

There is some surrounding text to give more information for the 3D viewer, such as transparency.

The file format is fully described in the corresponding PDS label file (file with the same name and LBL extension).

3.3.3 OBJ format

The OBJ format is composed of a table of vertices followed by a table of facets. The numbering of the vertices begins at "1" – the first vertex is given in the first line of the file and is number one. When a facet is said to contain vertex number 1, it refers to the first line of the file, where the first vertex is defined.

The file format is fully described in the corresponding PDS label file (file with the same name and LBL extension).

3.3.4 STL format

The STL file is composed of a list of facets. The file is a succession of 7 lines such as the ones below:

```
facet normal 0 0 0
outer loop
vertex -2.385834 -0.947531 -0.362904
vertex -2.386673 -0.953326 -0.360448
vertex -2.389075 -0.950796 -0.358577
endloop
```

endfacet

Each group defines a facet with 3 vertices that are listed per line.

3.3.5 SPICE DSK format (.BDS extension)

The .BDS file is the SPICE Shape model, the DSK (Digital Shape Kernel). This format is binary and has to be used with the SPICE software.
http://naif.jpl.nasa.gov/naif/index.html

END OF DOCUMENT