APPENDIX A

Materials list for the Freja satellite

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A1. Introduction

One part of the study on Space Craft Charging effects, carried out in co-operation with the IRF-K and FMI, Helsinki, and under contract of ESTEC, is to compare the actual, measured, charging effects on the Freja to the results from computer codes used for simulation of charging effects. The charging effects, as seen by the scientific instrumentation on board the satellite, are evaluated as functions of different plasma environments and of the particle bombardment. The code POLAR will be used to simulate the S/C charging for certain input parameters. In order to do this, knowledge of the surface material of the Freja S/C is needed. In this report a description of the Freja S/C is given and the different materials used on the outer surface. Also an estimate of the surface areas of these materials are given.

A2. The FREJA design

Freja is a sun-pointing space craft with the solar panels placed on a flat circular surface. The overall diameter is 2.2 metres. The solar panel deck constitutes the "upper" deck. The "lower" deck is connected to the upper via a central aluminium tube. Radially from this tube 4 webs are mounted between the decks. The lower deck is 1.2 m in diameter. The distance between the two decks is 0.44 m.

In the central tube two solid powered motors are mounted, one facing "upwards", one facing "downwards", both used to lift the space craft into the final orbit. Each motor has a nozzle made of composite material.
In the space between the decks and the webs, the different booms and scientific instruments and other system units are mounted.

An important design goal of the satellite was to have as much as possible of the outer surface electrically conductive in order to even out electrical charges induced by the plasma environment and prohibit differential charging. However, it is not possible to achieve a 100% coverage of the surface with conductive material, as insulating material must be used for certain purposes.

The solar panels are covered by an electrically conducting coating, the instrument electronics boxes are covered by a blanket that has an electrically conducting outer surface and parts of the structure are painted by conductive paint.

In the following, a more detailed description is given.

A3. The structure

The basic structure of the space craft is made of honeycomb aluminium material, which is light weight but very strong and stiff. Parts outside the blankets are painted with white conductive paint of type PCB-Z .

A4. Solar panels

There are 8 identical solar panels, each covered by solar cells of 0.19 m2 area giving a total of 1.52 m2. The total area of the panels is 1.65 m2.

Conductive coating by Indium Tin Oxide is applied to the cover glass facing the outer space.

A5. Blanket

A large part of the spacecraft is covered by blankets with a conductive outer surface. There are two different types of blankets:
- One consisting of 13 layers of aluminized Mylar foil with Dacronet spacers and one layer of TCC 1 mil. Kapton foil as the outermost layer.
- One consists of a single layer of TCC 1 mil Kapton foil (Equipment bay blanket).

The technical data of the blanket material used is as follows, data for the outermost layer (TCC 1 mil Kapton foil) is given:

Make:	Sheldahl, MN 55057 USA
Type:	TCC X 1.0 mil Kapton x vacuum deposited aluminium
Resistance:	<250 000 ohms/square (Typically ≈10 000 ohms/square)
Spec. weight	0.023 gms/In2

A6. White paint

White paint is used on some surfaces of the platform. It is of type PCB Z and produced in France. It has a resistance of 2 Ohms/square to 10 ohms/square dependent on thickness and application method.

A7. Materials and surface areas

a. Materials with conduction outer surface

Item	Size	Surf. Area	Material
Blanket			
Sheldahl, Type G410610			TCC, <250 kΩ/square
Between webs		2.80	
Top/bottom lower deck		2.70	
Structure			
Central tube inner side	NA	NA	Aluminised Kapton foil

Central tube outer side	NA	NA	Al, Blanket
Platform top	NA	NA	Al, Blanket
Solar cell support	NA	NA	Al, white paint
Platform bottom	NA	NA	Al, Blanket
Webs *4 (inner part)	NA	NA	Al, Blanket
Webs *4 (outer part)	NA	0.700	Al, white paint
Interface ring	NA	NA	Al
ADCS (Attitude determination and control systems)			
Spin coil	d=25, l=640	0.050	Inside platform
Precession coil	d=21, l=830	0.055	Blanket
Control box	=FSU		
SME Sun sensor			ITO tape grounded
SME Sun sensor			ITO tape grounded
SSE+SSH/ACR Sun sensor	90*60*35		Blanket
2-axis magnetom *2	62*35*32		Blanket
Nutation dampers *2	2* d=50, l=100 2* d=20, l=300		Inside platform Inside platform
Power system			
Solar power generators *8	A=0.2 m2, h=15	A=1.65	ITO Conducting coating
Switch card *2	=FSU		
Pyro *2	=FSU		
TDT *2	=FSU		
DC/DC converter	=FSU		
Ni/Cd battery *2	183*114*325	0.175	Inside platform
LiCFX Lithium battery	183*57*325	0.117	Blanket
TM/TC			
FSU	300*205*230	0.286	Inside platform
Coax. switches	51*48*42	0.011	Al, Blanket
Rx *2	114*64*46	0.046	Inside platform
Tx *2	89*64*34	0.032	Al, Blanket
S-band antenna *2	d=<100, l=<340		”Carbon fibre” weak cond
450 MHz antenna *2			Gold plated brass Insulator ø=30 mm x 15
Propulsion			
STAR 13A	maxdia=308, maxl=396		Titan
Nozzle (outside S/C)	d=100-208,l=240	0.36	(See list below - isolator)
S & A	140*92*75		TBD
STAR 6B	d=<57, l=<100		Al
Spinrock *4 + brackets	d=57, l=179		Stainless steel
Item	**Size**	**Surf. Area**	**Material**

F1 E-field exp.

Probes *6	d=60	0.068	Al, Graphite coating
Electr. box	200*140*140	0.123	Al, Blanket
Wire boom packets *6	303*127*180	1.063	Al, Blanket

F2 Magnetom. exp.

Stiff boom	d=30, l=1835	0.173	Carbon fibre, VDA x 25 µ x VDA
SME (probe)	91*110*66	0.039	Blanket
MSP (Electronics box)	260*130*200	0.172	Blanket

F3H Particle exp.

TICS incl dpl. mech.	d=120, l=384	0.157	Al, Blanket
MATE incl dpl. mech.	d=120, l=264	0.108	Al, Blanket
DPU	180*150*100	0.093	Al, Blanket

F3C Cold Plasma Anal.

STASER mech.	283*100*130	0.119	Metal, Al
STACER boom			Metal
CPA sensor	d=105, l=133	0.053	Al, alodine treatment
PCU (Power Control Unit)	200*200*100	0.120	Blanket

F4 Wave exp.

Stiff boom	d=30, l=1835	0.173	Carbon fibre
Search Coil Magn *3	20*20*270	0.065	Fibre gl, "gold foil"
Bracket	appr. 80*80*80	0.038	Al, "silver foil"
Pre-amp SCM	125*41*92	0.029	Al
Electr. box	200*200*141	0.153	Al, Blanket
Cyl Lang Probe	d=10, l=580	0.018	Carbon fibre
HF probe *2	d=25	0.004	Al, Graphite coating
HF boom *2	d=7, l=600	0.026	Fibre glass

F5 Imager

UV camera *2	260*120*140	0.265	Carbon fibre, Blanket
Electr. box	300*150*200	0.210	Al, Blanket
Earth sensor el.	128*108*42	0.034	Inside platform
Earth sensor	d=58, l=98	0.023	Blanket, Small part glass

F6 El Beam and Correl. Exp.

TESP sensor	d=120, l=330	0.230	See table below
Electr. box	170*120*122	0.090	Al, Blanket
Gun/detector *3	size=50*232*110	0.263	Al
UV photometer *2	d=18, l=50	0.006	Insulators but small

b. Materials with non-conducting outer surface.

Item	Size	Surf. Area	Material
External parts of equipment bay			
LSL Coax		0.0001	
Separation switch harness		0.0300	
Coax switches		0.0036	
Power splitter		0.0009	
Coaxes		0.0144	
TICS cable		0.0020	
Arming plugs		0.0020	
DC-magnetometer boom			
DC probe harness		0.0023	
Cable loops		0.0075	
CYLP pyro		0.0018	
Search Coil Magnetometer boom			
HF pyro		0.0018	
Bottom platform			
S-band antenna coax		0.0050	
Kevlar retention string		0.0004	
TESP cradle rubber		0.0006	
TESP rubber support		0.0010	
TESP cables		0.0050	
TESP backshell		0.0020	
TESP pyro		0.0015	
TESP kevlar string		0.0004	
LSL antenna base		0.0015	
MATE cable		0.0045	
MATE cradle support		0.0004	
STAR 6B nozzle		0.0100	
Top platform			
S-band antenna coax		0.0050	
Kevlar retention string		0.0004	
STAR 13A nozzle		0.1200	
STAR 13A harness		0.0150	
Solar panels			
Brackets		0.0058	
Rear side cabling		0.0110	
Top side TCC		0.0180	
Edge TCC		0.0285	

Blanket not grounded	0.05
Total area of non conducting material (insulators etc.)	**0.27**

APPENDIX B

Material parameters for POLAR

This appendix contains the baseline material specification used in the POLAR simulations of the Freja charging events using models Ar and Cr. Parameters are listed in the standard order for NASCAP and POLAR, also listed in Table 3. Parameters 17 - 20 (last row of four items in eatch material definition) are dummy placeholders not used in POLAR 1.3.7 (PUM p. 6.1-46). The format below is that used in an input file to the VEHICL module of POLAR (see PUM pp. 6.1-41).

```
comment 1. MATERIAL DEFINITIONS
comment ======================
comment (file: materials_q)
comment
comment Sources:
comment * NASCAP default values as defined in POLAR user's manual
comment     section 6.12.12.
comment * ESTEC materials list, updated 12/4/94 by G. Drolshagen.
comment
comment
comment 1.1 ALUM (aluminium)
comment --- --- --- --- ---
comment
comment Aluminium. Source: NASCAP
ALUM
1.0         1.0e-3      -1.0        13.0        0.97        0.3         154.0       0.8
220.0       1.76        0.244       230.0       4.0e-5      -1.0        1.e4        2.e3
1.E-13      1.          1000.       20.
comment
comment
comment 1.2 CFRP
comment --- ----
comment
comment Conducting carbon fibre. Source: ESTEC
CFRP
1.          .001        -1.         6.34        .7          .3          110.        1.9
300         1.04        .413        135.        7.2e-6      -1.         10000.      11000.
1.E-13      1.          1000.       20.
comment
```

```
comment
comment 1.3 CARB
comment --- ----
comment
comment Non-conducting carbon fibre. As CFRP but with parameters
comment 3 and 14 from CONT.
CARB
1.          .001        1.e-11  6.34   .7          .3          110.        1.9
300         1.04        .413           135.        7.2e-6      1.e15       10000.      11000.
1.E-13      1.          1000.          20.
comment
comment
comment 1.4 ITOC
comment --- ----
comment
comment Material coated with ITO. Measured SEE yields were rather
comment independent of underlaying material. Average SEE value taken.
comment Source: ESTEC
ITOC
1.          0.001   -1.  22.           2.5         0.3         50.         0.6
100.        1.6         0.49           123.        3.2E-5      -1.         10000.      2000.
1.E-13      1           1000           20
comment
comment
comment 1.5 BLAN
comment ---- ---
comment
comment Sheldahl aluminized Kapton foil (3 mil) with conductive
comment ITO coating. Source: ESTEC
BLAN
1.          .001        -1.            13.         3.2         .35         50          .6
100.        1.65        .244           230.        .00004      -1.         10000.      2000.
17.         18.         19.            20.
comment
comment
comment 1.6 PCBZ
comment --- ----
comment
comment White paint PCB-Z assumed to be conductive in space.
comment Source: ESTEC
PCBZ
3.5         1.0e-4      -1.0           5.0         2.2         0.3         50.0        0.5
100.0       1.55        0.244          230.0       2.0e-5      -1.0        1.e4        2.e3
17.         18.         19.            20.
comment
```

```
comment
comment 1.7 CONT
comment --- ----
comment
comment Generic Dielectric after 5 years in GEO environment
comment DERTS measurement show similar SEE yield curves for
comment different materials after contamination by UV,e,ions,outgassing.
comment Source: ESTEC
CONT
3.5        100.E-6    1.E-11     5.         2.2        0.25         70.          0.6
150.       1.8        0.455      140.       2.E-5      1.E+15   10000.          11000.
1.E-13     1.         1000.      20.
comment
```

APPENDIX C

Definition of Freja model A

Input file (to be linked to fort.20) for the VEHICL module of POLAR. This is for Freja model Ar. The material definitions should also be included here, but as they are reproduced in Appendix B, we have deleted them from this listing.

```
comment Freja model Ar
comment
comment
comment 1. MATERIAL DEFINITIONS
comment ======================

<MATERIAL DEFINITIONS GOES HERE>

comment
comment
comment 2. SPACECRAFT STRUCTURE DEFINITION
comment =================================
comment
comment 2.0 General notes
comment --- --- --- --- -
comment
comment 2.0.1 Scale
comment
comment To model a 220 cm diameter spacecraft in two grid units,
comment a resolution of 1 m in grid size is quite appropriate.
comment
comment 2.0.2 Coordinate system
comment
comment We use a coordinate system slightly differing from
comment the satelite coordinate system (c.f. Figure 12.1 in the
comment Freja Blue Book):
comment    Axis in our system    Corresponding sat coord axis
comment                x                          x
comment                y                          z
comment                z                          -y
comment The origins of the satellite and the used coordinate systems
comment are the same.
comment
comment
comment 2.1 Spacecraft model
comment --- --- --- ---- ---
comment All spacecraft is defined as a big rectangle,
comment consisting of four cubes. Bottom at y=-1, height 1.
rectan
corner -1 -1 -1
deltas 1 1 1
surface -x BLAN
surface -z PCBZ
surface -y PCBZ
```

```
surface +y ITOC
endobj
rectan
corner -1 -1 0
deltas 1 1 1
surface -x ALUM
surface +z BLAN
surface -y PCBZ
surface +y ITOC
endobj
rectan
corner 0 -1 -1
deltas 1 1 1
surface +x PCBZ
surface -z BLAN
surface -y PCBZ
surface +y ITOC
endobj
rectan
corner 0 -1 0
deltas 1 1 1
surface +x BLAN
surface +z PCBZ
surface -y PCBZ
surface +y ITOC
endobj
comment Then patch in some "details" on upper and lower deck:
wedge
corner 0 -1 0
face ALUM -1 0 -1
length 1 1 1
surface +y BLAN
surface -y BLAN
endobj
wedge
corner 0 -1 0
face ALUM -1 0 1
length 1 1 1
surface +y CONT
surface -y CARB
endobj
wedge
corner 0 -1 0
face ALUM 1 0 -1
length 1 1 1
surface +y CONT
surface -y BLAN
endobj
wedge
corner 0 -1 0
face ALUM 1 0 1
length 1 1 1
surface +y CARB
surface -y BLAN
endobj
endsat
```

APPENDIX D

Definition of Freja model B

Input file (to be linked to fort.20) for the VEHICL module of POLAR. The material definitions should also be included here, but as they are reproduced in Appendix B, we have deleted them from this listing.

```
comment FREJA MODEL B
comment
comment
comment
comment 1. MATERIAL DEFINITIONS
comment ======================
comment

<MATERIAL DEFINITIONS GOES HERE>

comment
comment
comment
comment 2. SPACECRAFT STRUCTURE DEFINITIONS
comment ===================================
comment
comment 2.1 Solar panels
comment ----------------
comment ITOC octagon with ALUM edge modelling the interface ring.
octagon
axis 0 -3 0  0 -2 0
width 14
side 6
surface + ITOC
surface - PCBZ
surface c ALUM
endobj
comment 2.2 Bottom platform and central tube
comment --------------------------------
octagon
axis 0 -3 0  0 2 0
width 10
side 4
surface + BLAN
surface - BLAN
surface c BLAN
endobj
comment 2.3 Webs
comment --------
comment
comment 2.3.1 Web 1
rectan
corner -1 -2 5
deltas 1 1 3
```

```
surface +x PCBZ
surface -x PCBZ
surface -y PCBZ
surface +z PCBZ
endobj
wedge
corner -1 -1 5
face PCBZ 0 1 1
length 1 3 3
surface +x PCBZ
surface -x PCBZ
endobj
comment 2.3.2 Web 2
rectan
corner 0 -2 -8
deltas 1 1 3
surface +x PCBZ
surface -x PCBZ
surface -y PCBZ
surface -z PCBZ
endobj
wedge
corner 0 -1 -5
face PCBZ 0 1 -1
length 1 3 3
surface +x PCBZ
surface -x PCBZ
endobj
comment 2.3.3 Web 3
rectan
corner 5 -2 0
deltas 3 1 1
surface +x PCBZ
surface -y PCBZ
surface +z PCBZ
surface -z PCBZ
endobj
wedge
corner 5 -1 0
face PCBZ 1 1 0
length 3 3 1
surface +z PCBZ
surface -z PCBZ
endobj
comment 2.3.4 Web 4
rectan
corner -8 -2 -1
deltas 3 1 1
surface -x PCBZ
surface -y PCBZ
surface +z PCBZ
surface -z PCBZ
endobj
wedge
corner -5 -1 -1
face PCBZ -1 1 0
length 3 3 1
surface +z PCBZ
```

```
surface -z PCBZ
endobj
comment 2.4 Bottom platform
comment -------------------
octagon
axis 0 2 0  0 3 0
width 10
side 4
surface + PCBZ
surface c PCBZ
endobj
comment 2.5 Top nozzle
comment --------------
comment Split in two to make it simple to change material of upper part
rectan
corner -1 -6 -1
deltas 2 1 2
surface +x CARB
surface -x CARB
surface -y CARB
surface +z CARB
surface -z CARB
endobj
rectan
corner -1 -5 -1
deltas 2 2 2
surface +x CFRP
surface -x CFRP
surface +z CFRP
surface -z CFRP
endobj
comment 2.6 Bottom nozzle
comment -----------------
rectan
corner -1 3 -1
deltas 1 2 1
surface +x ALUM
surface -x ALUM
surface +y ALUM
surface +z ALUM
surface -z ALUM
endobj
comment
comment 2.7 Insulating details
comment ---- ---- ---- ---- --
comment
comment The total exposed insulator area on Freja is around 0.28 m2,
comment of which the Star13A nozzle, whose conductive properties
comment after use is somewhat uncertain, contributes 0.12 m2.
comment This amounts to 0.28/0.157^2 = 11 unit surfaces in total,
comment of which about 5 are due to the nozzle. The y are distributed
comment as follows:
comment
comment          Place            m2      surfaces (dxmesh2)
comment
comment          Star13A nozzle   0.12    5
comment          Bays             0.05    2
comment          Bottom platform  0.02    1
```

```
comment                 Top platform       0.08       3
comment
comment To model this:
comment                 (a) For the nozzle: change material in 2.5
comment                 (b) For the rest: Add CONT squares
comment
comment 2.7.1 Insulators in bays
comment
comment These are added in the +-x bays
patchr
corner 4 0 -2
deltas 1 1 1
surface +x CONT
endobj
patchr
corner -5 0 1
deltas 1 1 1
surface -x CONT
endobj
comment
comment 2.7.2 Insulators on bottom platform
patchr
corner 1 2 1
deltas 1 1 1
surface +y CONT
endobj
comment
comment 2.7.3 Insulators on top platform
patchr
corner 2 -3 2
deltas 1 1 1
surface -y CONT
surface +y ITOC
endobj
patchr
corner -3 -3 2
deltas 1 1 1
surface -y CONT
surface +y ITOC
endobj
patchr
corner -1 -3 -4
deltas 1 1 1
surface -y CONT
surface +y ITOC
endobj
endsat
```

APPENDIX E

Definition of Freja model C

Input file (to be linked to fort.20) for the VEHICL module of POLAR. The material definitions should also be included here, but as they are reproduced in Appendix B, we have deleted them from this listing.

```
comment FREJA MODEL Cr
comment (As Cn but CPAI->PCBZ, solar panel support PCBZ, nozzle CARB)
comment
comment
comment 1. MATERIAL DEFINITIONS
comment ======================
comment

<MATERIAL DEFINITIONS GOES HERE>

comment
comment 2. SPACECRAFT STRUCTURE DEFINITION
comment ==================================
comment
comment 2.0 General notes
comment --- --- --- --- -
comment
comment 2.0.1 Scale
comment
comment Freja is less than 2.5 m wide, and we have 50 grid points
comment in the x and y directions. However, limitations in number
comment of surfaces (2500) and volume cells (2047) Polar 1.3.7 can
comment handle prohibits 5 cm as grid size: instead, we choose
comment 10 cm.
comment
comment
comment 2.0.2 Coordinate system
comment
comment We use a coordinate system slightly differing from
comment the satelite coordinate system (c.f. Figure 12.1 in the
comment Freja Blue Book). Furthermore, we do not use the same axes:
comment    Axis in our system    Corresponding sat coord axis
comment                x                          x
comment                y                          z
comment                z                          -y
comment The origins of the satellite and the used coordinate systems
comment are not the same: we have the origin at ysat = -3.
comment
comment
comment 2.1 Central tube
comment --- --- --- ----
comment Modelled as 1 big rectangle in this model (filled hole).
comment Bottom at y=-4, height 4. Figure CT22 can still be used,
comment but all the space should be filled with one rectangle.
rectan
```

```
corner -3 -1 -3
deltas 6 4 6
surface +x ALUM
surface -x ALUM
surface +y BLAN
surface -y BLAN
surface +z ALUM
surface -z ALUM
endobj
comment
comment 2.2 Lower platform
comment --- --- --- --- --
comment Defined as four rectangles plus four triangles
comment See figure LP21
comment
comment R1:
rectan
corner 2 -2 -2
deltas 4 1 4
surface +x PCBZ
surface -x PCBZ
surface +y PCBZ
surface -y BLAN
endobj
comment R2:
rectan
corner -2 -2 2
deltas 4 1 4
surface +y PCBZ
surface -y BLAN
surface +z PCBZ
surface -z PCBZ
endobj
comment R3:
rectan
corner -6 -2 -2
deltas 4 1 4
surface +x PCBZ
surface -x PCBZ
surface +y PCBZ
surface -y BLAN
endobj
comment R4:
rectan
corner -2 -2 -6
deltas 4 1 4
surface +y PCBZ
surface -y BLAN
surface +z PCBZ
surface -z PCBZ
endobj
comment T1:
wedge
corner 2 -2 2
face PCBZ 1 0 1
length 4 1 4
surface +y PCBZ
surface -y BLAN
```

```
endobj
comment T2:
wedge
corner -2 -2 2
face PCBZ -1 0 1
length 4 1 4
surface +y PCBZ
surface -y BLAN
endobj
comment T3:
wedge
corner -2 -2 -2
face PCBZ -1 0 -1
length 4 1 4
surface +y PCBZ
surface -y BLAN
endobj
comment T4:
wedge
corner 2 -2 -2
face PCBZ 1 0 -1
length 4 1 4
surface +y PCBZ
surface -y BLAN
endobj
comment Now compress to save space (p. 6.1-33)
compress
comment
comment 2.2 Upper platform
comment --- --- --- --- --
comment Defined as four rectangles plus four triangles
comment See figure UP21
comment
comment R1:
rectan
corner 2 3 -2
deltas 4 1 4
surface +x PCBZ
surface -x PCBZ
surface +y BLAN
surface -y PCBZ
endobj
comment R2:
rectan
corner -2 3 2
deltas 4 1 4
surface +y BLAN
surface -y PCBZ
surface +z PCBZ
surface -z PCBZ
endobj
comment R3:
rectan
corner -6 3 -2
deltas 4 1 4
surface +x PCBZ
surface -x PCBZ
surface +y BLAN
```

```
surface -y PCBZ
endobj
comment R4:
rectan
corner -2 3 -6
deltas 4 1 4
surface +y BLAN
surface -y PCBZ
surface +z PCBZ
surface -z PCBZ
endobj
comment T1:
wedge
corner 2 3 2
face PCBZ 1 0 1
length 4 1 4
surface +y BLAN
surface -y PCBZ
endobj
comment T2:
wedge
corner -2 3 2
face PCBZ -1 0 1
length 4 1 4
surface +y BLAN
surface -y PCBZ
endobj
comment T3:
wedge
corner -2 3 -2
face PCBZ -1 0 -1
length 4 1 4
surface +y BLAN
surface -y PCBZ
endobj
comment T4:
wedge
corner 2 3 -2
face PCBZ 1 0 -1
length 4 1 4
surface +y BLAN
surface -y PCBZ
endobj
comment Now compress to save space (p. 6.1-33)
compress
comment
comment 2.4 Support webs
comment --- --- --- ----
comment Each defined as two rectangles plus one triangle
comment See figure WB21
comment
comment 2.4.1 Web 1
comment
comment R11:
rectan
corner 3 1 0
deltas 5 2 1
surface +x PCBZ
```

```
surface +y PCBZ
surface +z PCBZ
surface -z PCBZ
endobj
comment R12:
rectan
corner 3 -1 0
deltas 3 2 1
surface +z PCBZ
surface -z PCBZ
endobj
comment T1:
wedge
corner 6 1 0
face PCBZ 1 -1 0
length 2 2 1
surface +z PCBZ
surface -z PCBZ
endobj
comment
comment 2.4.2 Web 2
comment
comment R21:
rectan
corner -1 1 3
deltas 1 2 5
surface +x PCBZ
surface -x PCBZ
surface +y PCBZ
surface +z PCBZ
endobj
comment R22:
rectan
corner -1 -1 3
deltas 1 2 3
surface +x PCBZ
surface -x PCBZ
endobj
comment T2:
wedge
corner -1 1 6
face PCBZ 0 -1 1
length 1 2 2
surface +x PCBZ
surface -x PCBZ
endobj
comment
comment 2.4.3 Web 3
comment
comment R31:
rectan
corner -8 1 -1
deltas 5 2 1
surface -x PCBZ
surface +y PCBZ
surface +z PCBZ
surface -z PCBZ
endobj
```

```
comment R32:
rectan
corner -6 -1 -1
deltas 3 2 1
surface +z PCBZ
surface -z PCBZ
endobj
comment T3:
wedge
corner -6 1 -1
face PCBZ -1 -1 0
length 2 2 1
surface +z PCBZ
surface -z PCBZ
endobj
comment
comment 2.4.4 Web 4
comment
comment R41:
rectan
corner 0 1 -8
deltas 1 2 5
surface +x PCBZ
surface -x PCBZ
surface +y PCBZ
surface -z PCBZ
endobj
comment R42:
rectan
corner 0 -1 -6
deltas 1 2 3
surface +x PCBZ
surface -x PCBZ
endobj
comment T4:
wedge
corner 0 1 -6
face PCBZ 0 -1 -1
length 1 2 2
surface +x PCBZ
surface -x PCBZ
endobj
comment Now compress to save space (p. 6.1-33)
compress
comment
comment 2.5 Solar panels
comment --- --- --- ----
comment Each quadrant defined as one rectangle plus three triangles
comment x and z surfaces put to ALUM to simulate interface ring
comment See figure SP21
comment
comment R1:
rectan
corner 6 3 -3
deltas 3 1 6
surface +x ALUM
surface +y ITOC
surface -y PCBZ
```

```
endobj
comment T11:
wedge
corner 6 3 3
face ALUM 1 0 1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment T12:
wedge
corner 6 3 6
face ALUM -1 0 -1
length 4 1 4
surface +y ITOC
surface -y ITOC
endobj
comment T13:
wedge
corner 3 3 6
face ALUM 1 0 1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment R2:
rectan
corner -3 3 6
deltas 6 1 3
surface +y ITOC
surface -y PCBZ
surface +z ALUM
endobj
comment T21:
wedge
corner -3 3 6
face ALUM -1 0 1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment T22:
wedge
corner -6 3 6
face ALUM 1 0 -1
length 4 1 4
surface +y ITOC
surface -y ITOC
endobj
comment T23:
wedge
corner -6 3 3
face ALUM -1 0 1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment R3:
```

```
rectan
corner -9 3 -3
deltas 3 1 6
surface -x ALUM
surface +y ITOC
surface -y PCBZ
endobj
comment T31:
wedge
corner -6 3 -3
face ALUM -1 0 -1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment T32:
wedge
corner -6 3 -6
face ALUM 1 0 1
length 4 1 4
surface +y ITOC
surface -y ITOC
endobj
comment T33:
wedge
corner -3 3 -6
face ALUM -1 0 -1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment R4:
rectan
corner -3 3 -9
deltas 6 1 3
surface +y ITOC
surface -y PCBZ
surface -z ALUM
endobj
comment T41:
wedge
corner 3 3 -6
face ALUM 1 0 -1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment T42:
wedge
corner 6 3 -6
face ALUM -1 0 1
length 4 1 4
surface +y ITOC
surface -y ITOC
endobj
comment T43:
wedge
corner 6 3 -3
```

```
face ALUM 1 0 -1
length 3 1 3
surface +y ITOC
surface -y PCBZ
endobj
comment Now compress to save space (p. 6.1-33)
compress
comment
comment 2.6 Engines
comment --- --- ---
comment Modelled as four rectangles, to make different choices
comment of material possible.
comment See figure EN21
comment
comment R0: upper central part
comment (main engine really titan)
rectan
corner -1 3 -1
deltas 2 2 2
surface +x ALUM
surface -x ALUM
surface +z ALUM
surface -z ALUM
endobj
comment R1: lower central part
rectan
corner -1 -3 -1
deltas 2 2 2
surface +x ALUM
surface -x ALUM
surface -y ALUM
surface +z ALUM
surface -z ALUM
endobj
comment R2: upper nozzle
rectan
corner -1 5 -1
deltas 2 1 2
surface +x CARB
surface -x CARB
surface +y CARB
surface +z CARB
surface -z CARB
endobj
comment R3: lower nozzle
comment (Much smaller than upper)
comment Only 1 area unit insulator
rectan
corner -1 -4 -1
deltas 1 1 1
surface +x CARB
surface -x CFRP
surface -y CFRP
surface +z CFRP
surface -z CFRP
endobj
comment Now compress to save space (p. 6.1-33)
compress
```

```
comment
comment 2.7 Interface ring
comment --- --- --- --- --
comment Modelled by having solar panel edges of Al in this version.
comment
comment
comment 2.8 Thermal blankets (between platforms)
comment --- --- --- ---- ---
comment Modelled as eight rectangles.
comment undefined double points (p. 6.1-38)
comment See figure BL21
comment
comment S1:
rectan
corner 3 -1 1
deltas 2 4 2
surface +x BLAN
surface +z BLAN
endobj
comment R1:
rectan
corner 0 -1 3
deltas 3 4 1
surface +x BLAN
surface +z BLAN
endobj
comment S2:
rectan
corner -3 -1 3
deltas 2 4 2
surface -x BLAN
surface +z BLAN
endobj
comment R2:
rectan
corner -4 -1 0
deltas 1 4 3
surface -x BLAN
surface +z BLAN
endobj
comment S3:
rectan
corner -5 -1 -3
deltas 2 4 2
surface -x BLAN
surface -z BLAN
endobj
comment R3:
rectan
corner -3 -1 -4
deltas 3 4 1
surface -x BLAN
surface -z BLAN
endobj
comment S4:
rectan
corner 1 -1 -5
deltas 2 4 2
```

```
surface +x BLAN
surface -z BLAN
endobj
comment R4:
rectan
corner 3 -1 -3
deltas 1 4 3
surface +x BLAN
surface -z BLAN
endobj
comment Now compress to save space (p. 6.1-33)
compress
comment
comment 2.9 Spacecraft system details
comment --- --- --- ---- --- --- ----
comment
comment 2.9.1 Sun sensors
comment
comment Sun-1
rectan
corner -4 4 1
deltas 1 1 1
surface +x ITOC
surface -x ITOC
surface +y ITOC
surface +z ITOC
surface -z ITOC
endobj
comment Sun-2
rectan
corner 1 4 3
deltas 1 1 1
surface +x ITOC
surface -x ITOC
surface +y ITOC
surface +z ITOC
surface -z ITOC
endobj
comment Sun-3
rectan
corner 0 -3 5
deltas 1 1 1
surface +x ITOC
surface -x ITOC
surface -y ITOC
surface +z ITOC
surface -z ITOC
endobj
comment
comment Now compress to save space (p. 6.1-33)
compress
comment
comment
comment Now compress to save space (p. 6.1-33)
compress
comment
comment 2.9.2 Insulators (all modelled as cont)
comment
```

```
comment See also nozzles and antennas
comment
comment Insulator IBP2, placed at random on bottom platform:
patchr
corner -3 -2 2
deltas 1 1 1
surface -y CONT
endobj
comment Insulator ITP2, placed at random on top platform
patchr
corner -4 3 0
deltas 1 1 1
surface +y CONT
surface -y PCBZ
endobj
comment Insulator ITP3, placed at random on top platform
patchr
corner 3 3 -1
deltas 1 1 1
surface +y CONT
surface -y PCBZ
endobj
comment Insulators in bays (2 area units for x facing, 1 for y facing)
comment See figure IB21
comment P1:
patchr
corner 2 0 3
deltas 1 1 1
surface +x CONT
surface +z CONT
endobj
comment P2:
patchr
corner -3 0 3
deltas 1 1 1
surface -x CONT
endobj
comment P3:
patchr
corner -3 0 -4
deltas 1 1 1
surface -x CONT
surface -z CONT
endobj
comment P4:
patchr
corner 2 0 -4
deltas 1 1 1
surface +x CONT
endobj
comment 2.9.3 TM antennas
comment
comment Bengt's paper give them as d<100, l<340, weakly conductive
comment  carbon fibre.
comment
comment
comment Bottom antenna
conductor 2
```

```
rectan
corner 2 -5 4
deltas 1 3 1
surface +x CFRP
surface -x CFRP
surface -y CFRP
surface +z CFRP
surface -z CFRP
endobj
comment Insulator IBP1, placed as to model insulation for bottom antenna
patchr
corner 2 -2 4
deltas 1 1 1
surface -y CONT
endobj
comment Top antenna
conductor 3
rectan
corner 2 4 -5
deltas 1 3 1
surface +x CFRP
surface -x CFRP
surface +y CFRP
surface +z CFRP
surface -z CFRP
endobj
comment Insulator ITP1, placed as to model insulation for top antenna
patchr
corner 2 3 -4
deltas 1 1 1
surface +y CONT
endobj
patchr
corner 2 4 -5
deltas 1 1 1
surface +z CONT
surface -z CONT
surface +x CONT
surface -x CONT
endobj
endsat
```

APPENDIX F

Input to event 3 simulation (model C)

Below is listed an input file ntin to the NTERAK module of POLAR. To run a simulation using this input, a Unix system command sequence may look like nterak < ntin, which must be run after proper execution of the VEHICL module, in this case using the model C listing (Appendix E) in the file fort.20. For details on how to run POLAR we refer to PUM. The file below is extensively commented, with references to relevant sections of PUM, in order to facilitate for users to reproduce - or challenge! - the results obtained here.

```
comment
comment
comment Freja Charging Simulation Input
comment === === === === === === === ===
comment
comment For charging event 3 : Corrected values
comment
comment Input file for POLAR/NTERAK
comment
comment All page and section references are to POLAR User's Manual
comment
comment General notes:
comment -Plasma general flow direction defined in ORIENT input, details
here
comment -Rij and Cij defined in input file for VEHICL, not here
comment
comment 1. General NTERAK settings
comment --- --- --- --- --- --- --
comment
comment To get abort if errors are detected, we run in batch mode
comment (p. 6.4-2)
batch
comment
comment Initialize all potentials and currents
comment (pp. 6.4-6, pp. 6.4-19, pp. 3.3-4)
comment   istart options (p. 6.4-7):
comment           new - resets all potentials and densities
comment           cont - keeps dens's and pot's of a previous run
comment   igical options (p. 6.4-20):
comment           yes - use neutral ion densities (neuden)
comment                 (default for istart new)
comment           shad - use geometrical shadowing (shado)
comment           no - no wake (for low density or no flow)
comment           oldi - use resulting densities of a previous run
comment                 (default for istart cont)
comment           olgi - use neutral ion densities of a previous run
istart new
igical yes
comment
```

```
comment Polar 1.3.7 has a parameter denmix (not to be confused with
comment the old parameter mixden) for stabilization of unstable
comment problems. Documentation in file Features in pol1.3.7 directory.
comment The variable denmix can take any value between 0 and 1. Some
comment denmix values: 1.0 = default, no mixing
comment                0.3 = useful for unstable problems
comment                0.0 = completely frozen wake structure
denmix 0.3
comment
comment Putting curshr all gives old Polar structure (as in manual),
comment while curshr sim is the recommended in version 1.3.7 (default)
curshr sim
comment
comment
comment
comment
comment
comment
comment
comment
comment 2. Plasma parameters
comment --- --- --- --- ----
comment
comment 2.1 Cold plasma (pp. 6.4-10)
comment
comment Density [m-3]:
dens 1.2e8
comment Electron temperature [eV] and Te/Ti in neutral density
calculation:
comment (p. 6.4-11, p. 6.4-25)
temp 0.3
temprat 1.
comment This gives Debye = 7.43*sqrt(0.3/30) m = 74 cm
comment Ions other than protons are oxygen:
amuion 16.0
comment Ratio of oxygen to hydrogen concentration:
comment (> 1.e10 => pure O+ plasma, p. 6.4-12)
ratih 2.0e10
comment
comment General flow direction defined in ORIENT, not here. Here is
specified:
comment (a) magnitude and (b) exact direction, i.e. everything allowed
that
comment leaves +z COMPONENT DOMINANT (p. 6.4-19). The magnitude is the
comment flow speed normalized to the ion acoustic speed S0 = sqrt(KTe/mi)
comment (eqn. 6 in p. 3.3-6).
comment vmach = vsat/S0 = vsat*sqrt(mi/KT)
comment vmach = 7000 * sqrt(16 * 1.67e-27/(1.6e-19 * 0.3)) = 5.2
vmach 0.0 3.6 3.8
comment
comment
comment 2.2 Hot electrons (pp. 6.4-13)
comment
comment Modelled as by equation 3.41-a. See also p. 6.4-13.
comment
comment Maxwellian density [m-3] and temperature [eV]:
den2 1.5e3
temp2 5.0e3
```

```
comment
comment Power law coefficient [m-2 eV-1 sr-1 s-1]:
powco 3.2e12
comment
comment Negative of power law exponent:
palpha 1.9
comment
comment Power law integration low and high end cutoffs [eV]:
pcutl 0.5
pcuth 6.5e4
comment
comment Coefficient for Gaussian [m-2 eV-1 sr-1 s-1]:
gauco 1.2e5
comment Gaussian peak position and width [eV]:
enaut 1.5e3
delta 3.0e3
comment
comment 2.3 Magnetic field (p. 6.4-18):
comment
comment Turn B-field on or off
bfield on
comment
comment Magnitude of B [G] (1 G = 100 nT, 25 uT = 0.25 G):
bmag 0.25
comment
comment Direction AFTER ORIENT ROTATION:
bdir  -0.1 0.62 -0.78
comment
comment Note: the magsth keyword (p. 6.4-49) is not supported
comment by current POLAR versions.
comment
comment
comment 2.4 Flow velocity
comment
comment See section 2.1 above.
comment
comment
comment 2.5 Sun
comment
comment Intensity of sunlight: (1 = solar constant, 0 = darkness)
comment (p. 6.4-16) Default is sunint 0.0
sunint 0.0
comment
comment Direction to the sun AFTER ORIENT ROTATION:
sundir 0 1. 0.1
comment
comment Shadowing of surfaces turned off if convex yes:
convex yes
comment
comment
comment
comment 3. Computation settings
comment --- --- --- --- --- ---
comment
comment 3.1 General wake and sheath settings
comment
comment Include the wake caused by the sheath?
comment Default is sthwake off (p. 6.4-21)
```

```
sthwake off
comment
comment Only calculate some ion densities?
comment Default is savset off (p. 6.4-24)
savset off
comment
comment Include ionization of neutrals in sheath? (p. 6.4-38)
comment Default is sheionz off, neutden 1.e12 [m-3], ionzcross 1.e-20
[m2]
sheionz off
comment
comment 3.2 Neuden module (pp. 5.6-1)
comment
comment Correct for E-field effects on neutral ion density?
comment (p. 6.4-22, pp. 5.6.17) Default is efldcor yes
efldcor yes
comment
comment Angular resolution of neutral density calculation (p. 6.4-22):
comment Default is nphi 36, ntheta 180
nphi 36
ntheta 180
comment
comment Extra vertices to object shadow (p. 6.4-23)
comment Default is nadd 2
nadd 5
comment
comment 3.3 Shado module (pp. 5.6-6)
comment
comment Number of points and angular steps for resolving object and
sheath
comment Default is nhexsh 6000, nphish 16 (p. 6.4-23)
nhexsh 6000
nphish 16
comment
comment 3.4 Initial settings
comment
comment To give PWASON an easier task of finding the field picture,
comment we may estimate by using random ion currents first (inpot pre).
comment Default is inpot cons. (p. 6.4-28)
inpot cons
comment
comment 3.5 Computational grid
comment
comment Points to add to the object definition grid:
comment (pp. 6.4-33)
nxadnt 5
nxadnb 5
nyadnt 5
nyadnb 5
nzadon 5
nztail 10
comment
comment
comment 4. Complementary model data
comment --- --- --- --- --- --- ---
comment
comment The spacecraft model may need complementary electrical data for
comment full specification. These should not be given here, but in the
```

```
comment input file for VEHICL.
comment (p. 6.4-30 - 32) (cards bias, cij, rij)
comment
comment
comment 5. PWASON control
comment --- --- ---- ----
comment
comment PWASON is the potential calculation module of NTERAK,
comment described in section 6.43.10.
comment
comment 5.1 Iterations
comment
comment Set maximum number of space charge iterations; should be
comment one for very low densities where space charge has little
comment impact. Default is maxits 3. (p. 6.4-41)
maxits 1
comment
comment Set minimum and maximum number of iterations in the Poisson
comment conjugate gradient solver (p. 6.4-41, 4.3-1). Higher values
comment of maxitc may be needed for more tenuous plasmas.
comment Default is minitc 2, maxitc 20.
maxitc 160
comment
comment Orders of convergence for conjugate gradient method
comment Default is 6
potcon 4
comment
comment Absolute convergence criterion (p. 6.4-42)
rdrmin 3.
comment
comment
comment 6. CURREN control
comment --- ---- --- ----
comment
comment CURREN is the ion current calculation module of NTERAK,
comment described in section 6.43.20.
comment
comment Set maximum number of particle pushing sequences:
comment Default is ipcnt 3 (p. 6.4-46)
ipcnt 5
comment Set sheath edge potential [V]. Default is psim
comment (p. 6.4-48)
sthpot psim
comment
comment Thermal spread of particles? Default is thrmsprd off.
comment (p. 6.4-82, 3.4-6, source: sthcal.f)
thrmsprd on
comment
comment Average sheath particles to create one macro particle?
comment Default is aveprtcl off (p. 6.4-82, 5.6-21, source: sthcal.f)
aveprtcl on
comment
comment Electron drift approximation cutoff (p. 6.4-82, 5.6-28, 4.5-20)
comment If rdmax2=N, drift orbits will be used if rge < sqrt(N),
comment while pushing (using the subroutine ebpush, see source file
comment ebpus.f) is used for rge > sqrt(N) (rge in dxmesh units).
comment Default is rdmax2 0.25. Lower value gives more accuracy
comment and longer calculation.
```

```
rdmax2 0.25
comment
comment
comment
comment
comment 7. CHARGE control
comment --- ---- --- ----
comment
comment CHARGE is the module for calculating the spacecraft response
comment to the plasma.
comment
comment Set current calculation model:
comment   spclim = space charge limited
comment       orblim = orbit limited
comment   orbspc = orbit limited renormalized by space charge limited
comment            total current
comment Default is spclim (p. 6.45-51, 5.7-3, 3.4-5)
spclim
comment
comment Timestep in charging equations [s]
comment (p. 6.4-52, 3.5-2, 4.5-39, 5.7-5)
comment Long step -> only end result interesting, default is deltat 1
deltat 5.e-4
comment
comment Maximum number of CHARGE iterations (p.6.4-52)
comment Default is maxitt 2.
maxitt 2
comment
comment Bound on charging voltage (p. 6.4-56):
comment vltfix -80
comment
comment Initial potential: (p. 6.4-26)
comment condv 1 0
comment
comment Artificial noise: (p. 6.4-55)
comment vwiggl 0.05
comment
comment 8. Do calculations
comment --- --- --- --- --
comment
comment Maximum allowed voltage change in one iteration
comment Default is dvlim 1000 (p. 6.4-53)
dvlim 30.
comment
comment Do calculations:
loop 20 pwason curren charge
comment
comment 9. Terminate run
comment --- --- --- ----
comment
endrun
```

APPENDIX G

Input to event 6b simulation (model A)

Below is listed an input file ntin to the NTERAK module of POLAR. To run a simulation using this input, a Unix system command sequence may look like nterak < ntin, which must be run after proper execution of the VEHICL module, in this case using the model A listing (Appendix C) in the file fort.20. For details on how to run POLAR we refer to PUM. The file below is extensively commented, with references to relevant sections of PUM, in order to facilitate for users to reproduce - or challenge! - the results obtained here.

```
comment
comment
comment Freja Charging Simulation Input
comment === === === === === === === ===
comment
comment For charging event 6 (high V): orbit 1666 091800
comment
comment Input file for POLAR/NTERAK
comment
comment All page and section references are to POLAR User's Manual
comment
comment General notes:
comment -Plasma general flow direction defined in ORIENT input, details
here
comment -Rij and Cij defined in input file for VEHICL, not here
comment
comment 1. General NTERAK settings
comment --- --- --- --- --- --- --
comment
comment To get abort if errors are detected, we run in batch mode
comment (p. 6.4-2)
batch
comment
comment Initialize all potentials and currents
comment (pp. 6.4-6, pp. 6.4-19, pp. 3.3-4)
comment   istart options (p. 6.4-7):
comment           new - resets all potentials and densities
comment           cont - keeps dens's and pot's of a previous run
comment   igical options (p. 6.4-20):
comment           yes - use neutral ion densities (neuden)
comment                 (default for istart new)
comment           shad - use geometrical shadowing (shado)
comment           no - no wake (for low density or no flow)
comment           oldi - use resulting densities of a previous run
comment                 (default for istart cont)
comment           olgi - use neutral ion densities of a previous run
istart new
igical yes
comment
```

```
comment Polar 1.3.7 has a parameter denmix (not to be confused with
comment the old parameter mixden) for stabilization of unstable
comment problems. Documentation in file Features in pol1.3.7 directory.
comment The variable denmix can take any value between 0 and 1. Some
comment denmix values: 1.0 = default, no mixing
comment                0.3 = useful for unstable problems
comment                0.0 = completely frozen wake structure
denmix 1.0
comment
comment Putting curshr all gives old Polar structure (as in manual),
comment while curshr sim is the recommended in version 1.3.7 (default)
curshr sim
comment
comment
comment
comment
comment
comment
comment
comment
comment 2. Plasma parameters
comment --- --- --- --- ----
comment
comment 2.1 Cold plasma (pp. 6.4-10)
comment
comment Density [m-3]:
dens 3.0e7
comment Electron temperature [eV] and Te/Ti in neutral density
calculation:
comment (p. 6.4-11, p. 6.4-25)
temp 0.3
temprat 1.
comment This gives Debye = 7.43*sqrt(0.3/30) m = 74 cm
comment Ions other than protons are oxygen:
amuion 16.0
comment Ratio of oxygen to hydrogen concentration:
comment (> 1.e10 => pure O+ plasma, p. 6.4-12)
ratih 2e10
comment
comment General flow direction defined in ORIENT, not here. Here is
specified:
comment (a) magnitude and (b) exact direction, i.e. everything allowed
that
comment leaves +z COMPONENT DOMINANT (p. 6.4-19). The magnitude is the
comment flow speed normalized to the ion acoustic speed S0 = sqrt(KTe/mi)
comment (eqn. 6 in p. 3.3-6).
comment vmach = vsat/S0 = vsat*sqrt(mi/KT)
comment vmach = 7000 * sqrt(16 * 1.67e-27/(1.6e-19 * 0.3)) = 5.2
vmach 0.0 1.35 5.04
comment
comment
comment 2.2 Hot electrons (pp. 6.4-13)
comment
comment Modelled as by equation 3.41-a. See also p. 6.4-13.
comment
comment Maxwellian density [m-3] and temperature [eV]:
den2 6.2e5
temp2 8.0e3
```

```
comment
comment Power law coefficient [m-2 eV-1 sr-1 s-1]:
powco 7.6e14
comment
comment Negative of power law exponent:
palpha 2.0
comment
comment Power law integration low and high end cutoffs [eV]:
pcutl 0.5
pcuth 2.0e4
comment
comment Coefficient for Gaussian [m-2 eV-1 sr-1 s-1]:
gauco 1.3e4
comment Gaussian peak position and width [eV]:
enaut 1.1e4
delta 1.5e3
comment
comment 2.3 Magnetic field (p. 6.4-18):
comment
comment Turn B-field on or off
bfield on
comment
comment Magnitude of B [G] (1 G = 100 nT, 25 uT = 0.25 G):
bmag 0.28
comment
comment Direction AFTER ORIENT ROTATION:
bdir  0.55 -0.83 -0.02
comment
comment Note: the magsth keyword (p. 6.4-49) is not supported
comment by current POLAR versions.
comment
comment
comment 2.4 Flow velocity
comment
comment See section 2.1 above.
comment
comment
comment 2.5 Sun
comment
comment Intensity of sunlight: (1 = solar constant, 0 = darkness)
comment (p. 6.4-16) Default is sunint 0.0
sunint 0.0
comment
comment Direction to the sun AFTER ORIENT ROTATION:
sundir 0 1. 0.1
comment
comment Shadowing of surfaces turned off if convex yes:
convex yes
comment
comment
comment
comment 3. Computation settings
comment --- --- --- --- --- ---
comment
comment 3.1 General wake and sheath settings
comment
comment Include the wake caused by the sheath?
comment Default is sthwake off (p. 6.4-21)
```

```
sthwake off
comment
comment Only calculate some ion densities?
comment Default is savset off (p. 6.4-24)
savset off
comment
comment Include ionization of neutrals in sheath? (p. 6.4-38)
comment Default is sheionz off, neutden 1.e12 [m-3], ionzcross 1.e-20
[m2]
sheionz off
comment
comment 3.2 Neuden module (pp. 5.6-1)
comment
comment Correct for E-field effects on neutral ion density?
comment (p. 6.4-22, pp. 5.6.17) Default is efldcor yes
efldcor yes
comment
comment Angular resolution of neutral density calculation (p. 6.4-22):
comment Default is nphi 36, ntheta 180
nphi 36
ntheta 180
comment
comment Extra vertices to object shadow (p. 6.4-23)
comment Default is nadd 2
nadd 2
comment
comment 3.3 Shado module (pp. 5.6-6)
comment
comment Number of points and angular steps for resolving object and
sheath
comment Default is nhexsh 6000, nphish 16 (p. 6.4-23)
nhexsh 6000
nphish 16
comment
comment 3.4 Initial settings
comment
comment To give PWASON an easier task of finding the field picture,
comment we may estimate by using random ion currents first (inpot pre).
comment Default is inpot cons. (p. 6.4-28)
inpot cons
comment
comment 3.5 Computational grid
comment
comment Points to add to the object definition grid:
comment (pp. 6.4-33)
nxadnt 6
nxadnb 6
nyadnt 6
nyadnb 6
nzadon 6
nztail 12
comment
comment
comment 4. Complementary model data
comment --- --- --- --- --- --- ---
comment
comment The spacecraft model may need complementary electrical data for
comment full specification. These should not be given here, but in the
```

```
comment input file for VEHICL.
comment (p. 6.4-30 - 32) (cards bias, cij, rij)
comment
comment
comment 5. PWASON control
comment --- --- ---- ----
comment
comment PWASON is the potential calculation module of NTERAK,
comment described in section 6.43.10.
comment
comment 5.1 Iterations
comment
comment Set maximum number of space charge iterations; should be
comment one for very low densities where space charge has little
comment impact. Default is maxits 3. (p. 6.4-41)
maxits 3
comment
comment Set minimum and maximum number of iterations in the Poisson
comment conjugate gradient solver (p. 6.4-41, 4.3-1). Higher values
comment of maxitc may be needed for more tenuous plasmas.
comment Default is minitc 2, maxitc 20.
maxitc 160
comment
comment Orders of convergence for conjugate gradient method
comment Default is 6
potcon 4
comment
comment Absolute convergence criterion (p. 6.4-42)
rdrmin 3.
comment
comment
comment 6. CURREN control
comment --- ---- --- ----
comment
comment CURREN is the ion current calculation module of NTERAK,
comment described in section 6.43.20.
comment
comment Set maximum number of particle pushing sequences:
comment Default is ipcnt 3 (p. 6.4-46)
ipcnt 3
comment Set sheath edge potential [V]. Default is psim
comment (p. 6.4-48)
sthpot psim
comment
comment Thermal spread of particles? Default is thrmsprd off.
comment (p. 6.4-82, 3.4-6, source: sthcal.f)
thrmsprd off
comment
comment Average sheath particles to create one macro particle?
comment Default is aveprtcl off (p. 6.4-82, 5.6-21, source: sthcal.f)
aveprtcl off
comment
comment Electron drift approximation cutoff (p. 6.4-82, 5.6-28, 4.5-20)
comment If rdmax2=N, drift orbits will be used if rge < sqrt(N),
comment while pushing (using the subroutine ebpush, see source file
comment ebpus.f) is used for rge > sqrt(N) (rge in dxmesh units).
comment Default is rdmax2 0.25. Lower value gives more accuracy
comment and longer calculation.
```

```
rdmax2 0.25
comment
comment
comment
comment
comment 7. CHARGE control
comment --- ---- --- ----
comment
comment CHARGE is the module for calculating the spacecraft response
comment to the plasma.
comment
comment Set current calculation model:
comment   spclim = space charge limited
comment       orblim = orbit limited
comment   orbspc = orbit limited renormalized by space charge limited
comment            total current
comment Default is spclim (p. 6.45-51, 5.7-3, 3.4-5)
spclim
comment
comment Timestep in charging equations [s]
comment (p. 6.4-52, 3.5-2, 4.5-39, 5.7-5)
comment Long step -> only end result interesting, default is deltat 1
deltat 1.e-4
comment
comment Maximum number of CHARGE iterations (p.6.4-52)
comment Default is maxitt 2.
maxitt 4
comment
comment Bound on charging voltage (p. 6.4-56):
comment vltfix -80
comment
comment Initial potential: (p. 6.4-26)
comment condv 1 -1000
comment
comment Artificial noise: (p. 6.4-55)
comment vwiggl 0.05
comment
comment 8. Do calculations
comment --- --- --- --- --
comment
comment Maximum allowed voltage change in one iteration
comment Default is dvlim 1000 (p. 6.4-53)
dvlim 50.
comment
comment Do calculations:
loop 20 pwason curren charge
comment
comment 9. Terminate run
comment --- --- --- ----
comment
endrun
```

APPENDIX H

Structure of Freja POLAR simulation file tree

This Appendix contains the file "contents" from the WP120 top directory, and the file "structure" in the directory POLARsimulations.

CONTENTS

The directory materials contains definition files of the different types of material used in the freja simulations with POLAR.

The directory POLARsimulations contains all the input and output files of the POLAR simulations for the freja charging events.

The directory spectra has subdirectories for the different events; 3,6a,6b,7 and 9 and these contain the electron spectra, the fits of the spectra and the matlab files that generate the fits. Further instructions for each event is given in the README.m file in each of the subdirectories.

The directory suchgr contains the files for the SUCHGR simulations of the freja charging events.

STRUCTURE

The data under POLARsimulations is structured in the following manner:

```
              POLARsimulations
       /              |             \
    modelA         modelB          modelC
                  [frejaBm.obj]
                 [oriin, oriout]
                 [shoin, shout]
                 [vehin, vehout]
        /       /        |      \      \
     event3  event6a  event6b  event7  event9
                    /       \
              orblim         spacelim
             /      \
   alt_m_no_vol       alt_r_init_vol
   [fort.#]
   [ntin.#]
   [ntout.#]
   [trout.#]
   [vehoutBm]
   [status.JCO]
```

The first level; modelA, modelB and modelC contaians the data for different simulations using different models of the freja spacecraft. The model is defined in the frejaBm.obj file in the model directory. The letter B stands for the model type and the letter m for the variation of this model type. The variation is described in the frejaBm.obj file. If there is more than one .obj file this implies that different variations were used in different simulations.[see wp120 documentation]
oriin is the input file to the orient module and oriout is the output.
shoin is the input file to the shontl module and shout is the output.

vehinA is the input file to the vehicl module and vehout is the output.

Second level; event3, event6a, event6b, event7, event9 contains the data for the different charging events simulated.
event3: 921205 02:38 Charging at sunset during auroral substorm.
event6a:930209 09:17 Beginning of an intense auroral inverted-V event.
event6b:930209 09:18 Peak of an intense auroral inverted-V event.
event7: 930218 09:32 Sunlight conditions during auroral inverted-V event.
event9: 921201 00:35 Charging during variation of plasma density.

Third level; orblim and spacelim divides the simulations into one cathegori that used orbit limited motion in the solutions and one with space limited motion. The difference between the two is described in wp120.

Fourth level; alt_m_no_vol, alt_m_init_vol etc. contains the simulation runs.
alt_m gives the specific variation of the model type used given by the frejaBm.obj file at the first level.
no_vol means that the simulation started with an initial voltage of the spacecraft of zero volts.
init_vol means that the initial voltage of the spacecraft is different from zero.
All the alt_r files are using corrected spectra.
Under modelA eventD are simulations of freja for the DMSP environment given in POLAR and for the DMSP satellite.

The fort.# files are the input and output files used by POLAR [see POLAR manual]

The ntin.# files are the input files to the nterak module. .s0 means start 0 and starts a simulation. the next are .c1 .c2 etc. meaning continue 1, continue 2 etc. These are fed to nterak whenever a simulation has stopped for any reason and POLAR has not yet found a stable solution. Only numerical parameters are changed in these. If numbers are skipped, for example .c3 .c5 this means that exactly the same file was used in between without any changes.

The ntout.# files are the corresponding output files from nterak.

The trout.# files are the corresponding output files from the trmtlk module.

The vehoutBm file is the output file from vehicl for the specific model variation used.

STATUS.JCO contains runtime status information.

APPENDIX J

Some notes on running POLAR/NTERAK

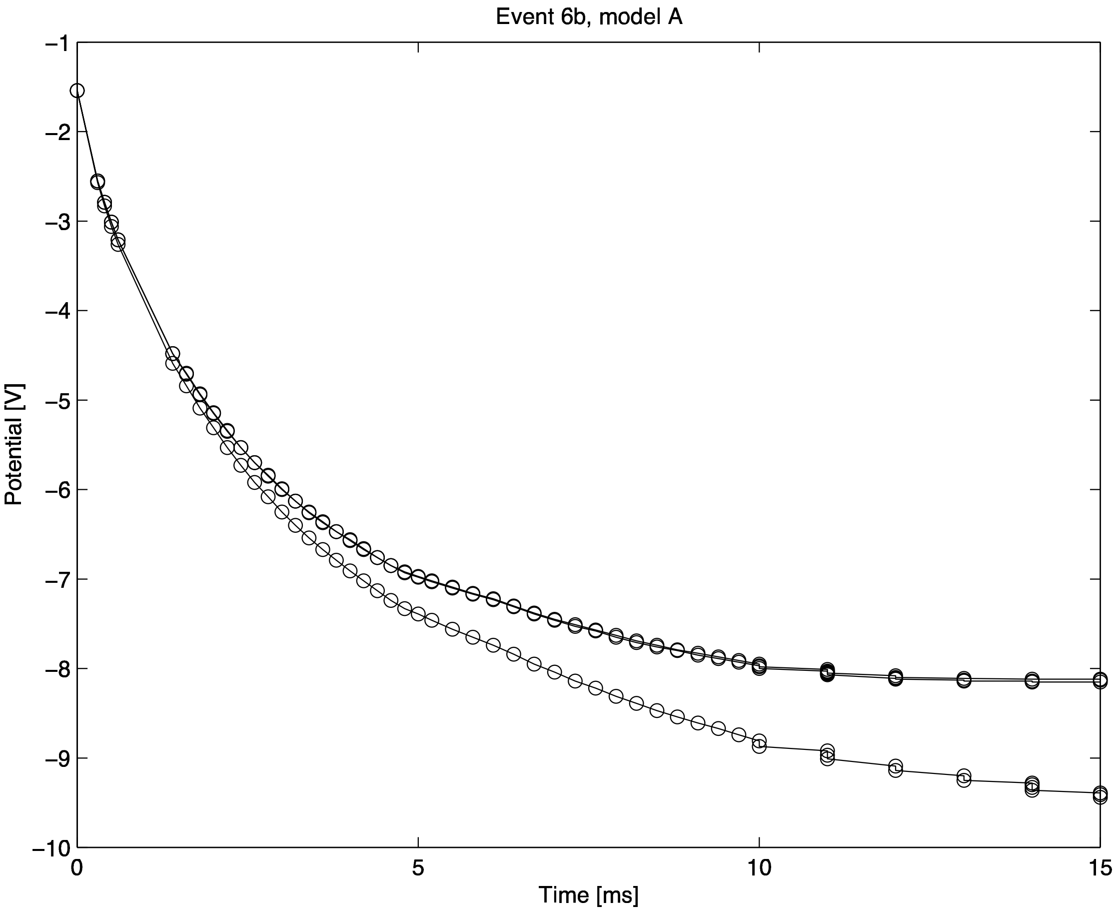

Figure J1. Time history of spacecraft charging for a spacecraft initially at ground potential placed in the environment of event 6b, as modelled by POLAR using Freja model A. The upper curve shows the potential of the spacecraft bulk, while the lower is the potential of the carbon fibre nozzle, here assumed to be almost non-conductive.

In the ideal case, POLAR/NTERAK should run smoothly and produce a charging history like the one seen above. In reality, several problems will occur. To keep on the track, a useful strategy is as follows:

-Save all your input and output files.

-When you need several runs: name your files according to the s0, c1, c2, c3, … convention

-If you have run your s0 start files succesfully, create a subdirectory, copy all the fort.* files there and run the c1 run there. Why? Because if c1 blows up (starts oscillate, or gets lost in some other way), you have lost the (often quite substantial) computer time invested in the s0 run. When c1 has finished to your liking, copy all fort.* files up to the main directory, start c2 and so on. This way a suddenly ill-behaved solution will not destroy a long day's work of fine simulations.

An example of a simulation sequence using prepared input files

```
vehicl < vehin | tee vehout
nterak < ntin.s0 | tee ntout.s0
trmtlk < trin | tee trout.s0
shontl < shoin | tee shout.s0
pstplot
mv PSTPLT ps.s0
cd subdir
cp ../fort.* .
nterak < ntin.c1 | tee ntout.c1
trmtlk < trin | tee trout.c1
shontl < shoin | tee shout.c1
pstplot
mv PSTPLT ps.c1
cp fort.* ../.
mv *.c1 ../.
nterak < ntin.c2 | tee ntout.c2
…
```

APPENDIX K

Matlab spectral plotting and fit routines

This appendix lists the files README.m, init.m and fx.m found in any event directory under <WP120maindirectory>/spectra/.

README.m

```
% This directory contains electron data and fits for
% Freja charging event 3.
%
% mate_data contains MATE electron data. First column
% is energy [eV], second is differential number flux
% [m-2 sr-1 s-1 eV-1]. Data is a six-second average.
%
% tesp_data contains TESP electron data. First column
% is energy [eV], second is differential number flux
% [m-2 sr-1 s-1 eV-1]. Data is a six-second average.
%
% init.m and fx.m are Matlab routines for plotting of
% data and visual fitting to the POLAR electron model.
% One first runs init from the Matlab command line,
% and then fx. The routine init initializes values of
% all the POLAR fit parameters, while fx does the actual
% plotting. One can change any of the POLAR fit parameters
% (dens, temp, powco, palpha, ...) on the command line and
% run fx again, which will plot the data and fit with the
% new values.
% Example:
% $ matlab
% >> init
% >> fx
% >> enaut = 3e6;
% >> fx
% >> powco = 1.2;
% >> fx
% Additional parameters that may be varied are:
% comp: comp=1 gives compensation for charging level
%       (default), comp=0 gives no compensation.
% Vsat: observed level of charging (negative, in Volts).
% xmin, xmax, ymin, ymax: plot limits.
%
% spectrum_raw.ps, spectrum_raw.eps, spectrum_corr.eps
% and spectrum_raw.ps are plots of the data data with
% POLAR electron expressions fitted. "corr" denotes that
% a correction for the observed charging level has been
% introduced, while "raw" indicates plots showing fits
% without such correction.
%
% Help.m prints README.m (this file) in the matlab command
% window.
```

init.m

```
% init - initialize parameters for event modelling for Polar

% Compensate for charging level? Yes if comp = 1, no if comp = 0.
% Note that data is not compensated: instead, the plot of the
% fit is modified in fx.

comp = 1;
Vsat = -25; % [V]

% Load data:

load tesp_data;
load mate_data;
Et = tesp_data(:,1)';
Fit = tesp_data(:,2)';
Em = mate_data(:,1)';
Fim = mate_data(:,2)';
negind = find((Et < -Vsat) | (Et < 50));
Et(negind) = [];
Fit(negind) = [];
negind = find(Em < -Vsat);
Em(negind) = [];
Fim(negind) = [];

% Initialize values:

% Cold plasma:
dens = 125e6;     % [m-3]
temp = 0.3; % [eV]
temprat = 1.0;    % Te/Ti

% Power law electrons:
powco = 2.7e11;   % [m-2 s-1 sr-1 eV-1]
palpha = 1.6;     % [negative of exponent]
pcutl = 0.5;      % [eV]
pcuth = 6.5e4;    % [eV]

% Maxwellian hot electrons:
den2 = 1.5e3;     % [m-3]
temp2 = 5e3;      % [eV]

% Gaussian hot electrons:
gauco = 1.2e5;    % [m-2 s-1 sr-1 eV-1]
enaut = 1.5e3;    % peak energy [eV]
delta = 3e3;      % e-folding width [eV]

% Constants:
qe = 1.6e-19;     % [C]
me = 9.1e-31;     % [kg]

% Plot limits:
xmin = min(Et)/1.5;
xmax = max(Em)*1.5;
ymin = min(min(Fim),min(Fit))/1.5;
ymax = max(max(Fim),max(Fit))*1.5;;
```

```
Fimin = 1;  % Lowest flux to plot

% Plot title:
titstr = sprintf('Freja charging event 3: data and parametric fit');
```

fx.m

```
% fluxplot - plot fluxes for event modelling for Polar

% Energy values:

logE = -1:0.01:7;
E = 10.^logE;
E0 = E;

% The model spectra are compared to observed spectra, which are
% influenced by the charging of the spacecraft. To model this
% influence, we compensate the energy for the charging level,
% if correction is asked for (see init.m). Thus E0 is the energy
% at the spacecraft of an electron that out in space has energy
% E. For a negative Vsat, E0 < E. The POLAR modelling is for
% the unperturbed distributions out in space, i.e. for E.
% Therefore, the application of the fitting expression should
% be to E, but the data must then be transformed to E0.

if(comp)
  E = E0 - Vsat;
  % Works only for Vsat < 0
end

% Modelled number fluxes:
%
% In SI units, we have
% Phic = dens * qe * E .* exp(-E/temp) / sqrt(2 * pi^3 * me * (qe *
temp)^3);
% with unit m-2 s-1 J-1. To get eV-1 instead, we should multiply by qe,
% which in total gives qe*qe/qe^(3/2) = sqrt(qe):

Phic = sqrt(qe) * dens * E .* exp(-E/temp) / sqrt(2 * pi^3 * me *
temp^3);
Phip = Fimin * ones(size(E));
ind = find(E>=pcutl & E<=pcuth);
Phip(ind) = powco * E(ind).^(-palpha);
Phim = sqrt(qe) * den2 * E .* exp(-E/temp2) / sqrt(2 * pi^3 * me *
temp2^3);
Phig = gauco * E .* exp(-(E - enaut).^2/delta^2);
Phi = Phic + Phip + Phim + Phig;

% The Phis are now fluxes out in the unperturbed plasma.
% If correction for the energy was used, we must correct
% the flux in order to get the flux at the spacecraft. Note
% that we want to plot Phi(E0) vs E0, as this obviously is
% what the detectors are measuring, but have calculated
% Phi(E) above. We then use Liouville's theorem to get
% Phi(E0)/E0 = Phi(E)/E => Phi(E0) = Phi(E) E0/E. This works
% also if no correction was done.
```

```
Phic = Phic .* E0 ./ E;
Phip = Phip .* E0 ./ E;
Phim = Phim .* E0 ./ E;
Phig = Phig .* E0 ./ E;
Phi = Phi .* E0 ./ E;

% Combine fit with TESP and MATE data in one plot:

loglog(E0,Phi,'r',E0,Phic,'c--',E0,Phip,'b--',E0,Phim,'m--',E0,Phig,'g--
');
hold on
loglog(Et,Fit,'ro',Em,Fim,'rx');
hold off
xlabel('E [eV]');
ylabel('Phi [(m2 s sr eV)-1]');
axis([xmin xmax ymin ymax]);
sc = sprintf('dens %.1e, temp %.1e, den2 %.1e, temp2
%.1e',dens,temp,den2,temp2);
sp=sprintf('powco %.1e, palpha %.1e, pcutl %.1e, pcuth
%.1e',powco,palpha,pcutl,pcuth);
sg = sprintf('gauco %.1e, enaut %.1e, delta %.1e',gauco,enaut,delta);
tx = 10^(0.95*log10(xmin) + 0.05*log10(xmax));
tyc = 10^(0.8*log10(ymin) + 0.2*log10(ymax));
typ = 10^(0.85*log10(ymin) + 0.15*log10(ymax));
tyg = 10^(0.9*log10(ymin) + 0.1*log10(ymax));
text(tx,tyc,sc);
text(tx,typ,sp);
text(tx,tyg,sg);
title(titstr);
```