TN-003. EFW Boom Deploy Sequence

Revision History:

- Rev A, John Bonnell, UCBSSL, 2007.
  - Initial version.
- Rev B, John Bonnell, UCBSSL, 7 Aug. 2007.
  - Added motorized axial boom deploy description.
  - Added total deploy operations time estimates from RBSP_EFW_Booms_001, rev B2, Draft.
  - Added DRAFT EFW Commissioning Plan, building on the Boom Deploy Sequence.
  - Minor additions and clarifications.
- Rev C, John Bonnell, UCBSSL, 22 Aug. 2007.
  - Addition of SDT steps to Commisioning plan.
  - Text on separation between AXB Deploy (commissioning phase) and AXB Trim (nominal ops phase) added.
- Rev D, John Bonnell, UCB SSL, 2 Sep 2012.
  - Update of deploy steps and spin rate waypoints to reflect ***RBSP_EFW_SYS_003AG_Mass.xlsx***.
  - Change to ***RBSP_EFW_SYS_003AG_Mass.xlsx*** from ***RBSP_EFW_BOOMS_001*** as the governing document for the boom deploys (***BOOMS_001*** content merged into ***SYS_003***).
  - Deleted provisional deploy plan schedule and merged with spin rate profile.
  - Deleted graphical representation of spin rate over deploy sequence and replaced with tabular data.

Summary:
The RBSP-EFW radial (spin plane, SPB) and axial (AXB) booms are deployed in stages. These stages are driven by the requirements to maintain reasonable spacecraft spin rates throughout the deploy sequence, to gather data regarding the electrostatic potential structure surrounding the spacecraft, and to gather data regarding the radial and axial antenna response at different deployed lengths.
The document (***RBSP_EFW_SYS_003xx_Mass.xlsx, RBSP_EFW_SYS_003*** hereafter) presents the deploy sequence and an analysis of the evolution of the mass properties and spacecraft dynamics throughout the entire deploy sequence. The latest revision of ***RBSP_EFW_SYS_003xx_Mass.xlsx*** shall be considered the primary quantitative reference for the RBSP-EFW deploy sequence.

Below, the basic steps of the RBSP-EFW deploy sequence are described, along with any pertinent operational requirements. In addition, because of the particular interest in the

spin rate range covered during the EFW deploy sequence a more detailed description of that variation is also included in this document (abstracted from ***RBSP_EFW_SYS_003***).

Also, a DRAFT EFW Commissioning Plan and Schedule is included for MDR planning purposes.

Deploy Sequence:

The Flight Rules for the EFW Deploy are relatively simple:

1. All steps of the EFW deploy shall occur in sunlight.
2. The Open Doors, Deploy-X, Deploy-Y, Deploy AXB, and SDT steps shall occur with near-real-time low-rate science data support in order to verify sensor and actuator operation.

Step 0: Initial Spin Up.

- Spin Up maneuver can be pulsed or continuous, depending upon RCS properties and predicted boom-spacecraft dynamics (eg. Polar EFI and Cluster-II EFW deploys used continuous thrusting, while THEMIS EFI used pulsed).

Step 1a: Open SPB Doors.

- Verify doors open by change in sensor response (floating potential and sunlit/shadow spikes) and actuator readback (door open switch).

Step 1b: Deploy both X axis SPB cables 4 m; spin down (see **Error! Reference source not found.** for details).

- On-board motor control program monitors deployed length of cable, and will temporarily stop one motor to allow the other to catch up, thus maintaining symmetric deploy.
- Spin down monitored in near real time and tracked against predictions in ***RBSP_EFW_Booms_001*** to verify that boom deploy is proceeding nominally.
- Motor current on actuator supply and deploy rate (elapsed time to achieve a given deployed length) monitored in near real time and tracked against ground test results to verify motor function.

Step 2: Deploy both Y axis SPB cables 4 m, spin down.

- Same motor control and verification as in Step 1b.

Step 3: Deploy X 3 m (7 m total); spin down.
Step 4: Deploy-Y 3 m (7 m total); spin down.

Step 5: Spin Up and Unfurling of Fine Wires.

- Fine wires between SPB spheres and preamps begin to unfurl when centrifugal force exceeds a known lower value, and are fully unfurled at a known upper value.

At this point in the deploy, the EFW sensors (spheres+fine wires) are out, and the instrument can actually measure electric fields.

At this point in the deploy, one begins to run Sensor Diagnostic Tests (SDTs). These tests are run axis-by-axis, typically taking 30-60 minutes per axis, in order to gather data regarding optimal current and voltage biasing for the EFW sensors. The SDTs are typically run after spin ups in order to minimize the time required to complete the tests (the SDT takes a fixed number of spins, rather than fixed amount of time, as the sensor biasing is held constant for a single spin before switching to the next bias setting). The SDTs shall be supported by Survey rate EFW telemetry, but need not be downlinked in real time.

There are three primary impacts that the SDTs can have on other instruments: first, the changes in the bias current to the EFW sensors will change the spacecraft floating potential and will impact the measurement of low-energy charged particles; second, the variable voltage biasing of the EFW photoelectron control surfaces has produced interesting features in the photoelectron return spectra on previous missions (photoelectron "lines" above the primary return spectrum; third, the abrupt changes in EFW sensor potential that occur during the current bias sweeps will lead to signals of significant amplitude on the single-ended and differential potential measurements.

Steps 6 to N: Stepwise deploy of X and Y cables by roughly 5 m per step until final lengths are achieved.

At this point in the deploy sequence, the radial EFW antennas are completely deployed, and the instrument is measuring 2D electric fields. The total time required to perform the deploy operations and spin-up maneuvers for the wire booms is on the order of 3.2 to 3.5 hours, depending upon whether spin-ups are performed with continuous or pulsed thrusting. Note that the actual deploy sequence will be longer than this due to the goal or gathering significant amounts of data (from a minimum of 1 hour to 1 to 2 orbits) at intermediate boom lengths to characterize the potential structure around the RBSP spacecraft, and the changes of that potential structure as the wire booms deploy.

Prior to step N+1, the predicted spacecraft attitude and dynamics (alignment of spin axis with SC Z-axis as deploy proceeds; estimated nutation frequency at end of SPB deploy) are compared with predicts in order to verify spacecraft MOIs and dynamics prior to AXB deploy.

Step N+1: AXB Deploy.

- The rigid whip and sensor sections of the AXBs are released from their folded down, stowed configuration, one at a time, starting with the forwards sensor.

- Successful deploy of the rigid whip and sensor sections confirmed via changes in near-real-time science data, engineering housekeeping (actuator readbacks), and any modest nutations induced by the deploy operation.
- The motorized main AXB stacer elements are released, and first-motion functionality (~10-cm (TBR) initial deploy) performed on both, one at a time.
- The motorized main AXB stacer elements are deployed alternately, at a rate of ~1 cm/s, to 5 m monopole length.

At this point, the EFW antennas are fully-deployed, and the instrument is measuring 3D electric fields.

Step N+2: AXB Trim.

- Based on initial Sensor Diagnostic Tests conducted over 4 to 6 orbits, the deployed length of the fore and aft AXB stacers will be trimmed via additional deploys of a few tens of cm. Based on subsequent performance over longer (weeks to months) time periods, additional length trims shall be performed as needed. These additional trim operations occur outside the nominal EFW Commissioning period, and should be considered part of nominal EFW instrument operations, much like the SDTs that are run both during the Commissioning period, as well as throughout the mission to optimize EFW DC and AC instrument performance.

Spin Rate Variation and Current Deploy Plan:

Figure 1: Summary of RBSP-EFW-SPB deploy steps, expected spin rates and schedule.

[RBSP_EFW_SYS_003AG_Mass.xlsx]SPB Deploy Summary						
EVENT	1-2 Pair Stroke [m]	3-4 Pair Stroke [m]	1-2 Pair Sphere Radius [m]	3-4 Pair Sphere Radius [m]	SPIN RATE [RPM]	Approx. Mission Day of Event
AB Deploy	0.00	0.00	0.905	0.905	7.00	**15**
CD Deploy	4.00	1.00	4.905	1.905	6.92	**15**
AB Deploy	7.00	4.00	7.905	4.905	6.73	**15**
CD Deploy	7.00	7.00	7.905	7.905	6.61	**15**
SPIN-UP/ Fine Wire Unfurl	**10.00**	**10.00**	**10.905**	**10.905**	**14.00**	**16**
AB Deploy	15.00	10.00	15.905	10.905	13.24	**17**
CD Deploy	15.00	15.00	15.905	15.905	12.57	**17**
AB Deploy	20.00	15.00	20.905	15.905	11.68	**18**
CD Deploy	20.00	20.00	20.905	20.905	10.91	**18,19**
AB Deploy	25.00	20.00	25.905	20.905	10.01	**19,20**
CD Deploy	25.00	25.00	25.905	25.905	9.25	**20**
AB Deploy	30.00	25.00	30.905	25.905	8.43	**20**
CD Deploy	30.00	30.00	30.905	30.905	7.74	**20**
SPIN-UP	**30.00**	**30.00**	**30.905**	**30.905**	**11.06**	**21**
AB Deploy	35.00	30.00	35.905	30.905	10.04	**21**
CD Deploy	35.00	35.00	35.905	35.905	9.19	**21**
AB Deploy	40.00	35.00	40.905	35.905	8.34	**22,23**
CD Deploy	40.00	40.00	40.905	40.905	7.64	**23**
AB Deploy	45.00	40.00	45.905	40.905	6.94	**23**
CD Deploy	45.00	45.00	45.905	45.905	6.36	**23**
AB Deploy	49.10	45.00	50.000	45.905	5.90	**24**
CD Deploy	49.10	49.10	50.000	50.000	5.50	**24**
FINAL SPIN ADJ (as needed)	**49.10**	**49.10**	**50.000**	**50.000**	**5.50**	**25**

NOTES:

(1) Mission Day assignments as per "RBSP_LEOps_timeline_20120830 as of 29 August 2012".

(2) Small differences in the third sig-fig of SPIN RATE expected between RBSP-A and RBSP-B due to measured differences in deployed mass properties.

(3) STROKE is deployed length of boom cable; RADIUS is distance of EFW sphere from SC Z-axis.

Aside on Cetrifugal Forces During Deploy:

Note that while the relative change in spin rate and centrifugal force is rather large during the EFW deploy, the absolute magnitudes are modest compared to other accelerations that one would expect to experience during other phases of the mission (launch, for example), and so this variation should have a modest effect upon the design of other spacecraft or instrument structures. Representative values of centrifugal acceleration are tabulated in Table 1.

Table 1: Near-Spacecraft Centrifugalal Accelerations During EFW Deploy

Spin Rate [RPM; rad/s]	Centripetal Acceleration [m/s^2; Gs]	
	1-m radius	4-m radius
5	0.27 (0.03)	1.08 (0.12)
15	2.46 (0.25)	9.84 (1.00)