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NATURAL ENVIRONMENT DESIGN CRITERIA FOR THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) DEFINITION AND PRELIMINARY DESIGN

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16. ABSTRACT

This document provides the natural environment design criteria requirements for use in the Advanced X-Ray Astrophysics Facility (AXAF) definition and preliminary design studies. It addresses the atmospheric dynamic and thermodynamic environments, meteoroids, radiation, magnetic fields, physical constants, etc., and is intended to enable all groups involved in the definition and preliminary design studies to proceed with a common and consistent set of natural environment criteria requirements.

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NATURAL ENVIRONMENT DESIGN CRITERIA FOR THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) DEFINITION AND PRELIMINARY DESIGN

1.0 PURPOSE AND SCOPES

This document is to define the natural environment design criteria for the AXAF. It will be reviewed and updated where warranted.

2.0 GENERAL

The natural environment criteria given here will be used in the definition and preliminary design of the AXAF. Where the natural environment design requirements are schedule, time, and orbit dependent, they are based on an initial launch in the second quarter of CY 1991. The Space Shuttle will place the AXAF into a near circular orbit with a nominal inclination of 28.5 deg. Initial insertion altitude shall provide a minimum 3-year orbital life above 400 km (216 NM) assuming a random tumble drag orientation and a $+2\sigma$ solar activity, unless onboard propulsion for orbit adjustment is provided. The AXAF shall be designed for an on-orbit operational life of 15 years.

Design value requirements of natural environment parameters not specifically defined in this document will be obtained from NASA TM 82473, "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development," 1982 Revision, and NASA TM 82478, "Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development," 1982 Revision (Volume I). The AXAF shall be designed with no operational sensitivity to natural environment conditions during assembly, checkout, launch, and orbital operations to the maximum degree practical. Any required natural environmental data not contained in the above documents or detailed herein shall be obtained from, or approved by, the Chief, Atmospheric Sciences Division (ED41), MSFC, and be requested through the cognizant NASA/MSFC AXAF Program Office prior to use. These requirements will be reflected in the next update of this document.

3.0 NEUTRAL ATMOSPHERE

The MSFC/J70 Reference Orbital Atmosphere Model (Section A.3, Appendix A, of NASA TM 82478) will be used to calculate ambient gas constituents, i.e., atomic oxygen, etc., number densities and total density of the orbital altitude atmosphere for AXAF's design requirements. Inputs required for the model calculations will be provided upon request.

3.1 Guidance and Control System (Low Inclination Orbit)

The design mean value of total density over an orbit to be used for control stability requirements determination is given in Table 1 for various orbital altitudes.

TABLE 1. DESIGN G&C SYSTEM MEAN TOTAL DENSITY FOR A LOW INCLINATION ORBIT

Orbital Altitude	Total Density (kg/m^3)
1100 km (594 n.mi.)	0.5189×10^{-13}
1000 km (540 n.mi.)	0.1018×10^{-12}
900 km (486 n.mi.)	0.2105×10^{-12}
800 km (432 n.mi.)	0.4567×10^{-12}
700 km (378 n.mi.)	0.1042×10^{-11}
600 km (324 n.mi.)	0.2522×10^{-11}
555 km (300 n.mi.)	0.3814×10^{-11}
500 km (270 n.mi.)	0.6596×10^{-11}
445 km (240 n.mi.)	0.1180×10^{-10}
407 km (220 n.mi.)	0.1792×10^{-10}

Ref $\bar{F}_{10.7}(230)$ $A_p(400)$

These values do not account for the within-orbit atmospheric density or geomagnetic storm variations. These design requirements are currently being developed and estimates are available, if required for specific analyses, upon request.

3.2 Reboost and Orbit Maintenance (Low Inclination Orbit)

The design steady-state values of total density to be used for AXAF design reboost and orbit maintenance requirements analyses are given in Figure 1, Design Reference Orbit Maintenance Steady-State Total Density. (These design values will be updated within two years after minimum of current solar cycle.) These steady-state density values do not account for the within-orbit density dynamics or geomagnetic storm variations. They represent average values of density over the globe. Estimates on the variations are available if required for specific analyses.

3.3 Contamination

The design values for on-orbit ambient atmosphere constituents number densities that should be assessed relative to potential contribution to contamination due to atomic oxygen, etc., gas properties are given in Figure 2, Constituent Number Density. Further details on short-term dynamics of constituent number densities for geomagnetic storms are available if required for specific analyses.

4.0 SPACECRAFT CHARGING

The AXAF's electronic systems and surface structures will be designed to minimize the effects of spacecraft charging due to the buildup of large differential potentials. (See section 2.9 of NASA TM 82478.)

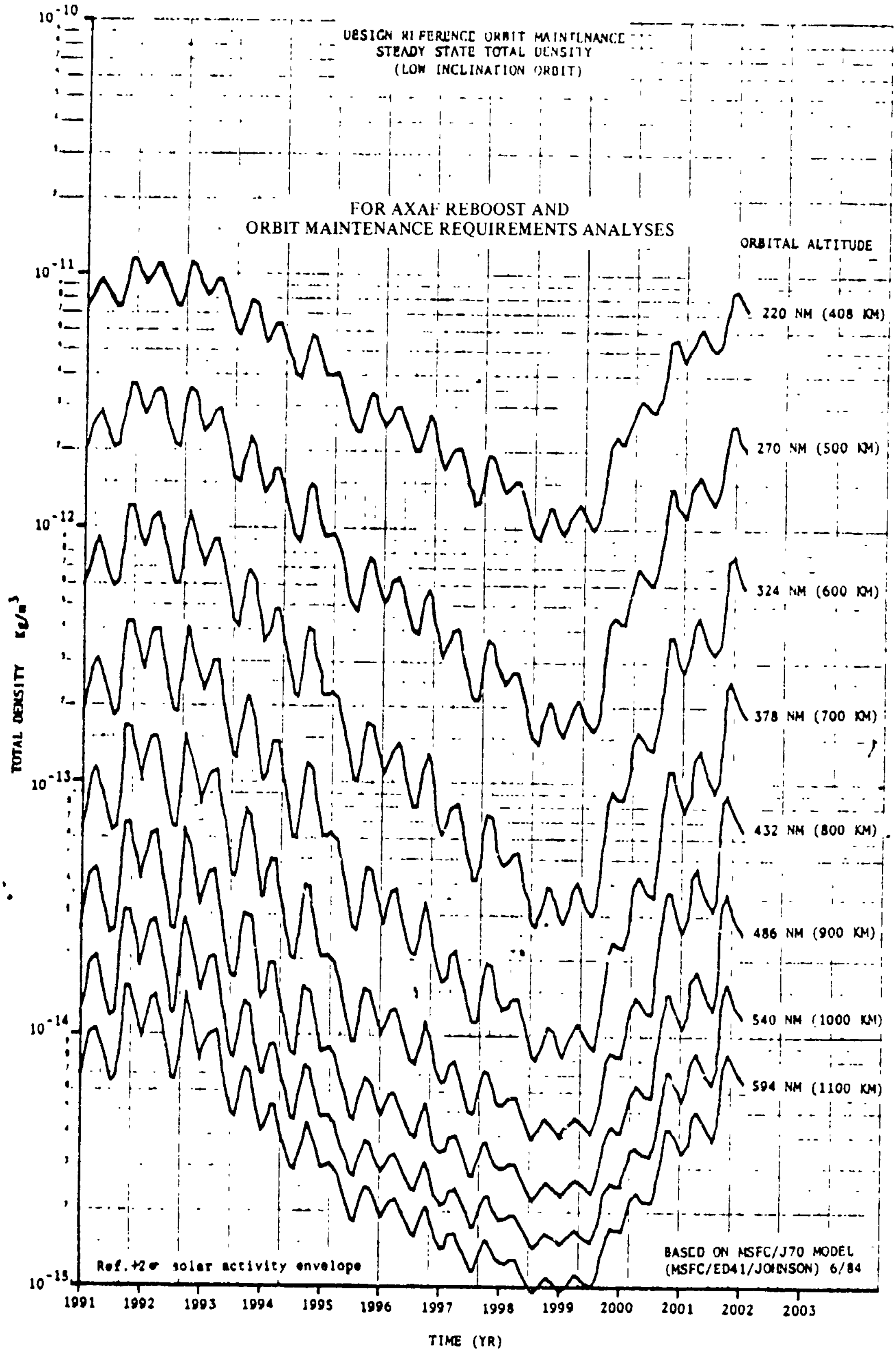
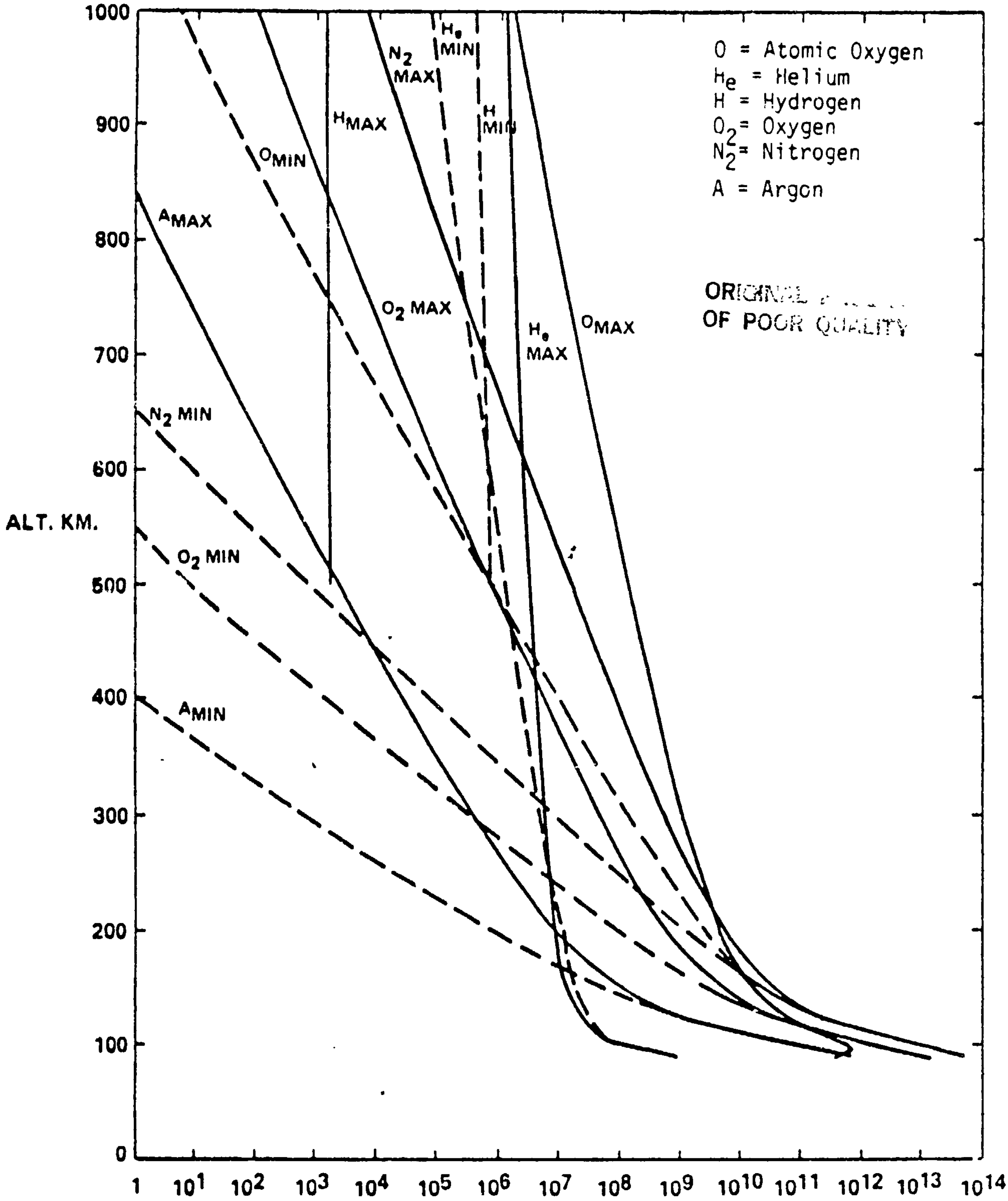


Figure 1. Design reference orbit maintenance steady state total density (low inclination orbit).



CONSTITUENT CONCENTRATION (cm^{-3})

USING MSFC–J70–3

FOR: MIN SOLAR CONDITIONS: 0400 hrs. USING $\bar{F}_{10.7}$ = 70 & $\bar{A}p$ = 0

MAX SOLAR CONDITIONS: 1400 hrs. USING $\bar{F}_{10.7}$ = 230 & $\bar{A}p$ = 35

Figure 2. Constituent number density.

5.0 RADIATION

The AXAF's electronic systems/modules will be designed to minimize the effects of charged particle radiation, plasma and electromagnetic fields. In addition to the following requirements, section 2.7 (Plasma and Electromagnetic Fields) and section 2.8 (Charged Particles) of NASA TM 82478 will be used to develop necessary protection to ensure that the safe dosage limits of the equipment are not exceeded over the 15-year design lifetime of the AXAF.

5.1 Cosmic Radiation

There are two types of cosmic radiation: galactic and solar. Galactic cosmic rays are those which have a steady stream flux intensity from outside the solar system. They are highest during periods of solar activity minimum and have energies up to 10^{20} eV. (See section 2.8.4 of NASA TM 82478.)

Solar cosmic rays come in bursts from the sun in solar flare events. A stream of solar cosmic rays reaches and envelops the Earth within minutes after a solar flare event; it reaches peak intensity in a few hours and then decays in 1 to 2 days. These rays are generally of lower energy than galactic cosmic rays. (See section 2.8.5 of NASA TM 82478.)

5.2 Trapped Radiation — Near Earth Orbit Environment

The radiation belts trapped near the Earth are approximately azimuthally symmetric, with the exception of the South Atlantic anomaly where the radiation belts reach their lowest altitude. The naturally occurring trapped radiation environments in the anomaly region remain fairly constant with time although they do fluctuate with solar activity. Electrons will be encountered at low altitudes in the anomaly region as well as in the auroral zones.

The trapped radiation environment will be calculated using the TRECO computer code (National Space Science Data Center, NASA-Goddard Space Flight Center) and merged with trajectory information to find particle fluxes and spectra for design use.

5.3 High Energy Solar Particle Event

High energy solar particle events are the emission of charged particles from disturbed regions fo the Sun during large solar flares. They are composed of energetic protons and alpha particles. Although they are relatively infrequent (34 events during solar cycle 19, and 20 events during solar cycle 20 with particle energies above 30 MeV), due to the 15-year design lifetime of the AXAF, the design will provide protection against these high energy solar particle events.

5.4 Electromagnetic Radiation

Design flux levels for the various spectral bands in the solar spectrum are given in section 1.5.3 of NASA TM 82478. However, the high flux levels for the radio (RF) spectral regions is primarily a result of man made Earth based and onboard radiation sources. Therefore, NASA SP-8092, "Assessment and Control of

Spacecraft Electromagnetic Interference" June 1972 shall be consulted to insure that an adequate EMI control program results to permit accomplishment of the AXAF operational requirements.

5.5 Solar Activity Data for AXAF Orbit Lifetime

This solar activity information is provided as input data in upper atmospheric models to insure compatibility between calculations of spacecraft orbital lifetime predictions. The associated orbital lifetime program for which these data are intended is given in Document No. N-240-1278, "Orbital Decay and Lifetime Predictions." Copies are available from MSFC's Orbital Mechanics Branch, Code EL25. The MSFC/J70 atmospheric model (NASA SP-8021) computes orbital density as a function of solar activity indicators. The model is available from MSFC's Atmospheric Sciences Division, Code ED41.

Table 2 gives the long-range statistical estimates of solar activity for the 97.7, 50, and 2.3 percentile values (this provides the 95 percent confidence interval) each month. Any questions on NASA/MSFC long-range statistical solar activity estimation procedure should be directed to MSFC's Atmospheric Sciences Division, Code ED41. These data are based upon information received from Herzberg Institute of Astrophysics, Canada, for $F_{10.7}$ and Institute fur Geophysik, Germany, for A_p.

TABLE 2. LONG-RANGE STATISTICAL ESTIMATION OF SOLAR ACTIVITY INDICES

TIME		10.7 CM SOLAR FLUX F10.7			GEOMAGNETIC INDEX AP		
		PERCENTILE			PERCENTILE		
		97.7	50	2.3	97.7	50	2.3
1991.0003	JA	211.4	132.6	89.8	20.7	12.7	10.7
1991.0837	FEB	214.8	134.9	90.9	20.8	12.6	10.6
1991.1670	MAR	218.1	137.1	92.1	21.0	13.4	10.7
1991.2503	APR	221.2	139.2	93.1	21.4	13.5	10.3
1991.3337	MAY	224.1	141.2	94.2	21.9	13.5	10.8
1991.4170	JUN	226.9	143.1	95.1	22.0	12.9	11.0
1991.5003	JUL	229.5	144.8	96.0	20.8	12.9	10.8
1991.5837	AUG	231.9	146.5	96.8	19.9	12.7	10.8
1991.6670	SEP	234.0	148.0	97.6	19.6	12.3	10.7
1991.7503	OCT	236.0	149.3	98.3	19.2	[illegible]	10.6
1991.8337	NOV	237.8	150.5	98.9	19.1	12.1	10.7
1991.9170	DEC	239.3	151.5	99.4	18.9	12.2	11.1
1992.0003	JAN	240.6	152.4	99.8	18.7	12.4	10.8
1992.0837	FEB	241.6	153.1	100.2	18.5	12.5	[illegible]
1992.1670	MAR	242.3	153.6	100.4	18.5	12.4	10.6
1992.2503	APR	242.7	153.9	100.6	18.2	12.5	10.3
1992.3337	MAY	242.9	154.0	100.6	18.1	12.6	10.5
1992.4170	JUN	239.0	152.5	96.2	18.6	12.7	11.2
1992.5003	JUL	234.2	150.5	96.1	19.1	12.6	11.3
1992.5837	AUG	230.8	148.8	95.6	19.5	12.9	11.2
1992.6670	SEP	231.2	143.7	93.1	20.1	13.2	11.4
1992.7503	OCT	230.7	141.7	90.9	20.8	13.3	11.6
1992.8337	NOV	228.2	140.2	89.8	21.2	13.4	11.7
1992.9170	DEC	226.2	138.3	92.2	21.0	13.9	[illegible]
1993.0003	JAN	225.7	136.4	89.7	20.3	13.8	11.8
1993.0837	FEB	224.5	134.5	87.4	20.5	14.1	12.0
1993.1670	MAR	223.2	132.9	89.9	21.7	14.3	12.1
1993.2503	APR	219.9	126.9	88.6	22.5	13.9	12.0
1993.3337	MAY	215.0	125.6	84.9	22.5	14.2	11.5
1993.4170	JUN	211.4	124.5	85.0	22.1	14.2	11.2
1993.5003	JUL	205.9	124.1	83.2	21.5	13.9	11.1
1993.5837	AUG	200.8	123.5	84.8	21.3	13.7	11.3

TABLE 2. (Concluded)

TIME		10.7 CM SOLAR FLUX F10.7 PERCENTILE 97.7	50	2.3	GEOMAGNETIC INDEX AP PERCENTILE 97.7	50	2.3
1993.6670	SEP	195.4	125.9	82.8	21.9	13.3	11.1
1993.7503	OCT	189.9	124.9	81.6	22.9	13.5	11.4
1993.8337	NOV	185.5	123.8	79.7	23.3	13.5	11.4
1993.9170	DEC	180.8	122.7	78.3	23.2	13.5	11.4
1994.0003	JAN	176.4	121.5	77.0	23.1	13.5	11.0
1994.0837	FEB	176.7	117.2	76.6	22.9	13.1	10.7
1994.1670	MAR	178.1	118.2	75.5	21.6	13.0	10.9
1994.2503	APR	177.6	116.7	76.0	20.1	13.8	11.1
1994.3337	MAY	175.5	115.4	75.3	19.5	14.0	11.6
1994.4170	JUN	171.4	116.8	73.1	19.6	13.7	11.6
1994.5003	JUL	165.8	114.7	73.8	19.9	13.4	11.4
1994.5837	AUG	161.9	112.7	70.8	20.3	13.5	11.3
1994.6670	SEP	160.8	113.4	71.1	20.5	13.6	11.4
1994.7503	OCT	159.9	109.5	71.7	20.8	13.6	11.4
1994.8337	NOV	158.1	108.1	70.5	20.9	13.5	11.2
1994.9170	DEC	155.6	104.2	70.0	21.4	14.2	11.1
1995.0003	JAN	151.4	100.7	70.7	22.0	14.0	11.5
1995.0837	FEB	145.9	99.7	70.4	21.8	13.3	11.5
1995.1670	MAR	139.8	96.8	68.8	21.8	13.2	11.4
1995.2503	APR	133.8	97.8	69.9	22.0	13.0	11.4
1995.3337	MAY	128.6	98.4	72.5	22.3	12.3	11.1
1995.4170	JUN	126.3	98.7	72.5	22.6	12.1	11.3
1995.5003	JUL	124.7	96.1	71.6	23.3	12.3	11.0
1995.5837	AUG	122.2	93.6	71.5	24.0	12.2	11.2
1995.6670	SEP	119.9	91.4	71.6	24.4	11.7	11.2
1995.7503	OCT	118.4	90.7	71.4	24.7	11.7	11.2
1995.8337	NOV	117.5	88.6	70.5	24.6	11.7	11.2
1995.9170	DEC	117.5	87.5	70.0	24.2	12.2	11.2
1996.0003	JAN	116.3	86.3	70.1	23.4	12.2	11.8
1996.0837	FEB	116.5	86.3	70.5	22.6	12.7	11.4
1996.1670	MAR	117.5	86.6	69.8	21.9	12.8	11.2
1996.2503	APR	117.9	87.2	69.7	21.6	12.2	11.1
1996.3337	MAY	118.0	86.3	68.2	21.2	11.9	11.2
1996.4170	JUN	117.7	85.4	68.5	20.9	12.0	11.3
1996.5003	JUL	116.8	83.0	67.6	20.3	12.1	10.5
1996.5837	AUG	115.5	82.1	68.4	19.6	12.4	9.8
1996.6670	SEP	113.5	82.6	67.9	19.6	12.5	9.6
1996.7503	OCT	109.2	81.8	67.4	19.6	12.7	9.1
1996.8337	NOV	103.5	81.2	67.3	19.4	12.9	9.1
1996.9170	DEC	98.2	79.9	67.4	19.0	12.8	8.8
1997.0003	JAN	98.1	79.9	67.0	18.5	12.6	8.7
1997.0837	FEB	98.8	78.3	67.1	17.6	12.6	9.3
1997.1670	MAR	100.0	77.4	67.1	16.9	12.6	10.1
1997.2503	APR	100.4	76.9	67.3	16.4	12.5	10.5
1997.3337	MAY	98.3	76.6	66.7	16.6	12.6	10.1
1997.4170	JUN	95.2	76.3	66.9	16.8	12.7	9.8
1997.5003	JUL	92.3	76.0	67.1	17.0	12.5	9.4
1997.5837	AUG	91.0	75.6	67.2	17.3	12.4	8.9
1997.6670	SEP	91.4	75.1	66.9	17.6	12.1	9.1
1997.7503	OCT	91.6	73.8	66.8	17.5	12.0	9.3
1997.8337	NOV	91.2	73.2	66.9	17.3	11.7	9.3
1997.9170	DEC	90.8	72.6	67.1	16.8	11.6	9.3
1998.0003	JAN	90.2	72.9	66.7	16.0	11.5	9.1
1998.0837	FEB	[illegible]	71.8	67.2	14.6	11.3	9.1
1998.1670	MAR	88.5	71.6	67.2	13.5	11.0	9.1
1998.2503	APR	87.5	71.3	67.1	13.6	10.6	8.9
1998.3337	MAY	86.3	70.5	67.2	13.3	10.4	8.5
1998.4170	JUN	84.7	70.4	67.4	12.8	10.0	8.1
1998.5003	JUL	82.6	70.4	67.8	12.6	9.5	8.1
1998.5837	AUG	80.0	70.1	67.7	12.3	9.6	8.0
1998.6670	SEP	77.6	70.3	68.0	11.7	9.8	8.3
1998.7503	OCT	76.7	70.8	67.8	11.2	10.0	8.6
1998.8337	NOV	76.4	71.7	67.7	11.0	10.2	8.5

NOTES FOR TABLE 2

A. The MSFC solar flux $\bar{F}_{10.7}$ and geomagnetic index $\bar{A}_p$ long range statistical estimations are based upon a historical 10.7 cm solar flux and geomagnetic index data base. Both estimates represent smoothed values over a 13-month period.

B. Some space platform orbital lifetime predictions require long-term estimates of solar activity for input to the associated orbital density model. This is accomplished by assuming an initial Epoch for the cycle 22 maximum to occur in May 1992. Cycle 22 is the computed empirical percentiles of 2.3, 50, and 97.7 based on the recorded past 20 cycles of activity. The tie-in of Cycle 21 with Cycle 22 is accomplished by a cubic curve fit between an inflection point on the estimated curve and the mean cycle maximum.

C. The dynamics of orbital density as represented by variation in daily $F_{10.7}$ and the three-hourly A_p inputs required for the atmospheric model are not represented by the smoothed statistical estimates given in these tables. This dynamic component of the total density level cannot be projected with any acceptable degree of statistical confidence as a function of time into the future using existing techniques.

D. For design lifetime purposes, the calculations relative to a spacecraft's orbital altitude should use the 97.7 percentile estimate of future solar activity. After launch the statements on remaining lifetime are given in terms of the probability that a spacecraft's lifetime will equal or exceed a given date or dates depending on program management requirements. Data are given in this memorandum to permit both program uses.

E. For the subject of the memorandum, and to maintain as realistic as practical the initialization date for the peak $F_{10.7}$ (13 month) solar flux on cycles 21 and 22, May 1981 is used for cycle 21 maximum, which is the current peak for $F_{10.7}$.

F. As recommended by MSFC's Atmospheric Sciences Division, ED41, Table 2 now contains the actual distribution of deviations from the nominal for the lower 2.3 percentile and the upper 97.7 percentile.

6.0 METEOROIDS

The AXAF will be designed to prevent loss of functional capability for all items critical to maintaining minimum operational support. The AXAF will otherwise be designed for at least a 0.95 probability of no penetration during the 15-year on-orbit design lifetime. The meteoroid flux model given in Figure 2-14, page 2-22, of NASA TM 82478 will be used (see section 2.6 of NASA TM 82478). It is further defined in NASA SP-8013, "Meteoroid Environment Model."

The logarithmic cumulative flux distribution model for the sporadic meteoroid population is given by the expressions:

a) $\mathrm{Log}_{10}N = -14.41 - 1.22\ \mathrm{Log}_{10}m$; for $10^{-6} < m \leq 10$

b) $\mathrm{Log}_{10}N = -14.34 - 1.58\ \mathrm{Log}_{10}m - 0.063\ (\mathrm{Log}_{10}m)^2$; for $10^{-12} < m \leq 10^{-6}$

where N is the cumulative flux, $m^{-2} s^{-1}$ (2π st) and m is mass, g. The sporadic flux is omnidirectional and the AXAF in orbit will be partially shielded by the Earth. The extent of the shielding is a function of altitude, and the shielded flux is equal to $(\frac{1+\cos\theta}{2})N$ where:

$$\sin\theta = \frac{R}{R + H}$$

R = Radius of the Earth and H = altitude of AXAF above Earth's surface.

The average hourly rate of meteoroids increases at times during a calendar year due to meteoroid streams as previously noted. Their periods of activity and peak fluxes are given in Table 2-3, page 2-20, of NASA TM-82478, where Fmax is the ratio of the stream to the sporadic meteoroid cumulative flux levels. Note that there is little or no enhancement of the sporadic population for masses less than 10^{-6} gm during stream activity.

Meteoroids are assumed to be spherical in shape and to have a bulk mass density of 0.5 gm/cc. However, this does not apply to micrometeoroids (<50 μ diameter) and it is generally assumed that a density of 2 gm/cc is more appropriate. The average atmospheric entry velocity of sporadic meteoroids is 20 km/sec, which is the value generally used to assess impact damage to spacecraft in Earth orbit. Stream meteoroids generally enter much faster as is seen in Table 203, page 2020, NASA TM-82478.

Space debris has become a significant factor of concern in recent years. The flux of space debris may exceed that of meteoroids. Therefore, NASA JSC Design Standard 20001 "Orbital Debris Environment for Space Station" should be consulted to insure that an overall AXAF design for both space debris and micrometeoroids damage protection results which will permit accomplishment of the AXAF operational requirements.

6.1 Pressure Storage Tanks

The AXAF's pressurized storage tanks will be designed to ensure no gas or liquid leak from meteoroid impact damage which will affect the on-orbit performance of AXAF.

6.2 Functional Capability

The probability of no penetration shall be assessed on each AXAF element in terms of the criticality of loss for its functional capability.

7.0 MAGNETIC FIELD

On-orbit AXAF design torques, surface charges, and induced electrical potential due to operating in the Earth's magnetic field shall be developed based on information given in section 2.7.1 of NASA TM 82478. Additional details are provided in NASA SP-8017, "Magnetic Fields Earth and Terrestrial," and NASA SP-8018, "Spacecraft Magnetic Torques." The International Geomagnetic Reference Field 1980 (see reference 2-32 of NASA TM 82478) will be the basis for the magnetic field model spherical harmonic coefficients. It is recommended that 15 terms be used in the spherical harmonic expansion to establish AXAF design conditions.

8.0 SPACE THERMAL AND PRESSURE ENVIRONMENT

The space thermal and pressure environment to be used for AXAF's design, including solar radiation. Earth's albedo and radiation, and space sink temperature and pressure, are given in Table 4 (see sections 1.5 and 2.5 of NASA TM 82478).

TABLE 4. SPACE THERMAL AND PRESSURE ENVIRONMENT

Environmental Parameter and Units	Value
Solar radiation, Btu/ft^2-hr	443.7
Earth albedo, percent	30
Earth radiation, Btu/ft^2-hr	77
Pressure, torr	10^{-10}
Space sink temperature, °R	0

9.0 PHYSICAL CONSTANTS

The values given in section 1.3 and section 2.3 of NASA TM 82478 will be used for the AXAF design performance analyses.

10.0 GROUND HANDLING AND TRANSPORTATION ENVIRONMENTS

The AXAF's and components thereof shall be protected from or designed to accommodate the applicable ambient natural environments for the locations involved in fabrication, storage, transportation, and assembly as given in NASA TM 82473 to insure no adverse natural environment impacts on the AXAF's operational performance.