I. INTRODUCTION

The Flight Dynamics Facility (FDF) of the Flight Dynamics Division (FDD), Code 550 of the Goddard Space Flight Center provides acquisition data to tracking stations and orbit and attitude products and services to scientists and mission support elements. It also performs orbit and attitude determination and analysis. I was assigned to spend my summer as a member of the North Carolina A & T Graduate Intern Program and work on a project that would be of mutual benefit to me as a student and to NASA personnel. My project was to determine a method to use to find the spacecraft entry and exit times of the aurora zone. To get familiar with the information, I read various books on the aurora, and orbit determinations. One of the books called "Spacecraft Attitude Determination and Control" by James R. Wertz, helped me to get familiar with the terminology and mathematical equations used for my project.

II. BACKGROUND INFORMATION

The Fast Auroral Snapshot Telescope (FAST) is the second mission of the Small Class Explorer (SMEX) program. It is designed to be a 1-yr. mission with launch currently planned for September, 1994. Furthermore, the assumed orbital elements for current studies are listed below:

- **Epoch:** Midpoint of Northern Campaign: JAN. 15, 1994 0HR. 0 MIN. 0 SEC.
- **Semimajor Axis:** 8653.166 KM
- **Eccentricity:** 0.222462 DEG
- **Inclination:** 83.00000 DEG
- **RA of Ascending Node:** 84.21000 DEG
- **Argument of Perigee:** 288.5400 DEG
- **Mean Anomaly:** 0.000000 DEG

(These elements reflect a 350km x 4200km orbit where apogee and perigee precess through two revolutions per year). FAST was developed for the investigation of the plasma physics of auroral phenomena at extremely high time and spatial resolutions, utilizing fast data sampling and to investigate the plasma physics at low altitude auroral zone. The project scientists have a way of determining when the fast spacecraft enters and exits the aurora zone. These scientists will be located at Poker Flats (Alaska) for the Northern Campaign. The Northern Campaign is defined to be the 60 days period centered around January 15, 1995. During the Northern Campaign, apogee will be over the North Pole. The Mission Operation Manager (MOM) and Flight Operation Team (FOT) stationed at Goddard would like to have their own
ESTIMATE OF THE SPACECRAFT ENTRY AND EXIT TIMES THROUGH THE AURORA ZONE. THE FLIGHT DYNAMICS FACILITY HAS BEEN REQUESTED TO PROVIDE THE MOM AND FOT WITH THIS INFORMATION.

TO MEET FAST'S NEEDS THE PROJECT IS CONSIDERING THE FOLLOWING TRACKING STATIONS LOCATIONS TO SUPPORT FAST: POKER FLATS (ALASKA), SANTIAGO (CHILE), CANBERRA (AUSTRALIA), WALLOPS ISLAND (VIRGINIA), AND GOLDSTONE (CALIFORNIA). THE TRANSPORTABLE TRACKING EQUIPMENT IS AN ANTENNA DISH AND OTHER EQUIPMENT THAT CAN BE TRANSPORTED FROM ONE PLACE TO ANOTHER WILL BE POSITIONED AT POKER FLATS. TRACKING DATA CONSISTS OF MEASUREMENTS SUCH AS DOPPLER, ANGLES OR RANGE WHICH WE USED IN THE ORBIT DETERMINATION (OD) SYSTEM TO PROVIDE POSITION AND VELOCITY OF THE SPACECRAFT AT A GIVEN TIME OR AN EPHEMERIS FOR A SPECIFIED PERIOD OF TIME. THESE GROUND STATIONS SEND COMMANDS UP TO FAST. THEY PROCESS THE RETURN SIGNAL TO PROVIDE TRACKING AND TELEMETRY DATA.

III. STATEMENT OF PROBLEM (MY SUMMER PROJECT)


IV. METHODOLOGY


\[ \mathbf{u}_y \times \mathbf{u}_z = \mathbf{u}_x \]  \hspace{1cm} (EQ. 1-1)

THE MAGNETIC NORTH POLE AWAY FROM THE SUN, IS THE AURORA AXIS. THESE COMPUTATIONS WERE USED TO CONSTRUCT FIGURE 1 WHICH SHOWS THE RIGHT HAND COORDINATE SYSTEM AND THE 4 DEGREES ROTATION. THE REASON FOR THE 4 DEGREES ROTATION IS BECAUSE THE SCIENTISTS STATE THAT THE AURORA CONE IS AFFECTED BY THE SOLAR WINDS, WHICH ARE PARTICLES CONSISTING MAINLY OF PROTONS AND ELECTRONS THAT FLOW OUT FROM THE SUN WITH A SUPersonic SPEED, PUSHING THE MAGNETIC FIELD. THE MAGNETIC NORTH POLE POSITION DOESN'T CHANGE IN THIS CASE, BUT IT IS USED TO DETERMINE WHERE THE AURORA AXIS IS LOCATED. THE ROTATION IS AS FOLLOWS:

\[
\begin{bmatrix}
1 & 0 & 0 \\
0 & \cos(\phi) & \cos(\phi) \\
0 & -\sin(\phi) & \cos(\phi)
\end{bmatrix}
\begin{bmatrix}
U_M \\
\end{bmatrix} =
\begin{bmatrix}
U_A \\
\end{bmatrix}
\] (EQ. 1-2)

WHERE PHI IS THE ROTATION ANGLE, UM IS THE UNIT VECTOR OF THE MAGNETIC NORTH POLE, AND UA IS THE RESULTANT UNIT VECTOR FOR THE AURORA AXIS.

NOTE: IF THERE IS NO ROTATION OF 4 DEGREES, THEN THE AURORA AXIS IS AT THE RIGHT ASCENSION AND DECLINATION OF THE MAGNETIC NORTH POLE.

NEXT, COMPUTE THE SEPARATION ANGLE BETWEEN THE AURORA AXIS AND THE SPACECRAFT POSITION. Hence, check the position of the spacecraft at a given time. TO DETERMINE IF THE SPACECRAFT IS IN/OUT OF THE AURORA CONE, GET THE DOT PRODUCT OF THE AURORA AXIS AND THE SPACECRAFT POSITION. THE DOT PRODUCT IS USED BECAUSE WE WILL BE ABLE TO DETERMINE THE SEPARATION ANGLE. THE SEPARATION ANGLE IS OBTAINED BY TRANSFORMING THE DOT PRODUCT EQUATION:

\[
\begin{align*}
UA \cdot S/C &= \begin{cases}
|UA| |S/C| \cos(\Theta), & \text{if } UA \neq 0 \text{ and } S/C \neq 0 \\
0, & \text{if } UA = 0 \text{ or } S/C = 0
\end{cases} \\
-1 &\text{ (\Theta) } = \cos \left( \frac{(UA \cdot S/C)}{(|UA| |S/C|)} \right) \quad (\text{EQ. 1-3})
\end{align*}
\]


\[
t(n) + 1' = T \quad (\text{EQ. 1-4})
\]

WHERE t(n) IS EQUAL TO THE EPOCH, AND T IS THE RESULTANT TIME. THIS PROCESS CONTINUES UNTIL WE FIND A GOOD APPROXIMATION. THE TIME AND THE POSITION OF THE SPACECRAFT IS TAKEN FROM THE EPHEMERIS FILE WHERE AS THE SUN POSITION IS TAKEN FROM THE SOLAR LUNAR PLANETARY FILE (SLP). THESE POSITIONS MUST BE TAKEN AT CORRE-
V. EXAMPLE:

GIVEN: UA CONE = 23 DEGREES HALF-ANGLE
UA POS. = ROTATE MNP 4 DEGREES AWAY FROM THE SUN

EPOCH: JAN. 15, 1994 0HR. 0 MIN. 0 SEC. GREENWICH MEAN TIME (GMT)

<table>
<thead>
<tr>
<th>RIGHT ASCENSIONS</th>
<th>DECLINATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNP POS. = 289.3 DEG</td>
<td>78.6 DEG</td>
</tr>
<tr>
<td>SUN POS. = 296.5 DEG</td>
<td>-21.2 DEG</td>
</tr>
<tr>
<td>GNP POS. = 0.0 DEG</td>
<td>90.0 DEG</td>
</tr>
<tr>
<td>S/C POS. = -49.97 DEG</td>
<td>-70.34 DEG</td>
</tr>
</tbody>
</table>

BY EQUATION 1-1, WE CAN APPLY THE CROSS PRODUCT OF THE TWO VECTORS:

0.4162961, -0.834205, -0.361662) X (0.00000, 0.00000, 1) = UX

WHERE UX = (-0.834205, -0.4162961, 0.000000) IS THE NEW UNIT VECTOR. THE MAGNETIC NORTH POLE UNIT VECTOR IS

UM = (0.06532854, -0.1865492, 0.9802712).

THIS UNIT VECTOR UM IS ROTATED 4 DEGREES ABOUT THE NEW UNIT VECTOR UX. THE RESULTANT UNIT VECTOR IS

UA = (-0.5372502, -0.6299052, -0.4476070)

WHERE UA IS THE AURORA AXIS. FROM THIS RESULT, ONE CAN CONSTRUCT THE AURORA CONE WITH THE 23 DEGREES HALF ANGLE.

SINCE WE KNOW THE POSITIONS OF THE CONE AND THE SPACECRAFT, WE CAN FIND THE ANGLE BETWEEN THEM BY USING DOT PRODUCT FROM EQUATION 1-3. HERE IS THE FOLLOWING

UA = (-0.5372502, -0.6299052, -0.4476070)

AND

S/C = (0.21637380, -0.2575849, -0.9417178)

WHERE UA AND S/C ARE DEFINED ON PAGE 3. THE SEPARATION ANGLE BETWEEN THE TWO DATA IS 60.21419 DEGREES. SINCE THE ANGLE IS GREATER THAN 23 DEGREES, WE ARE OUT OF THE CONE. THIS PROCESS CONTINUES UNTIL THE SEPARATION ANGLE IS LESS THAN OR EQUAL TO 23 DEGREES.
VI. SUMMARY

AUGUST 6, 1991

CODE 554.2 BLDG 23

BY MATTIE BOOKER

FAST AURORA ZONE

ANALYSIS
MISSION LIFE: 1 YEAR

PERIOD OF ORBIT: 2 HRS. 13 MINS. 133 MINS.

APOGEE: 4200 KM
PERIGEE: 350 KM

INCLINATION: 83 DEGS.

(+30 days)
NORTHERN CAMPAIGN: JAN. 15, 1995
LAUNCH DATE: SEPT. 1994

FAST AURORAL SNAPSHOT TELESCOPE

BACKGROUND
WITH AN ESTIMATE OF ENTRY & EXIT TIMES
TO PROVIDE FOR LOCATED AT GODDARD

PURPOSE

& EXIT TIMES OF THE AURORA ZONE
TO DETERMINE THE SPACECRAFT ENTRY

TO MEET THE PROJECT REQUIREMENT:
INVESTIGATE A CONCEPTUAL APPROACH
(RESEARCH & DEVELOPMENT)

STATEMENT OF PROBLEM
[Rotation Matrix] \[ \text{MAG. N. POLE} = \text{AURORA AXIS} \]

\[ \text{RA OF SUN X GEO. N. POLE} = \text{ROTATION AXIS} \]

To Find Aurora Cone Axis:

**Methodology**
SEPARATION ANGLE < 23 DEG. ; OUT

SEPARATION ANGLE ≥ 23 DEG. ; IN

AND S/C REFERENCED TO CENTER OF THE EARTH
WHERE i & j ARE UNIT VECTORS FOR AURORA AXIS

θ = j

1

0

BETWEEN CONE AND SPACECRAFT:

To find separation angle, θ.

METHODOLOGY (CON'T)
SUMMARY

Support of the FDD Fast Requirement Algorithm may be implemented in

Specifications for Software

FDD can now complete requirements

Entry & exit times

Identified methods for determining

Cone was defined