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The objective of the CAMP program is to demonstrate the feasibility of reusable Ada software parts in a real-time embedded application area; the domain chosen for the demonstration was that of missile flight software systems. This required that the existence of commonality within that domain be verified (in order to justify the development of parts for that domain), and that software parts be designed which address those areas identified. An associated parts system was developed to support parts usage. Volume 1 of this document is the User's Guide to the CAMP Software parts, Volume 2 is the Version Description Document; Volume 3 is the Software Product Specification; Volumes 4-6 contain the Top-Level Design Document; and, Volumes 7-12 contain the Detail Design Documents.

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SOFTWARE DETAILED DESIGN DOCUMENT

FOR THE

MISSILE SOFTWARE PARTS

OF THE

COMMON ADA MISSILE PACKAGE (CAMP) PROJECT

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AIR FORCE ARMAMENT LABORATORY
Air Force Systems Command ▮ United States Air Force ▮ Eglin Air Force Base, Florida

SOFTWARE DETAILED DESIGN DOCUMENT

FOR THE

MISSILE SOFTWARE PARTS

OF THE

COMMON ADA MISSILE PACKAGE (CAMP)
PROJECT

CONTRACT F08635-86-C-0025

CDRL SEQUENCE NO. C007

30 OCTOBER 1987

Prepared for

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Eglin AFB, Florida 32542

Prepared by

McDonnell Douglas Astronautics Company
P.O. Box 516
St. Louis, MO 63166

88 4 6 126

PREFACE

This document specifies the detailed design of the missile software parts identified during the Common Ada Missile Packages (CAMP) program.

This document contains data generated under the work task described by sections 5.3.1.2 and 5.3.2.3 of DOD-STD-2167, Defense System Software Development. It has been prepared in accordance with DI-MCCR-80031, Software Detailed Design Document.

The structure of DI-MCCR-80031 requires tailoring to meet the needs of reusable software components. The DID is intended for use in describing the design of a single application Computer Software Configuration Item (CSCI). The DID has, therefore, been tailored for describing the design of parts used individually or on a group basis. In addition, elements of DI-MCCR-80031 were already incorporated into the paragraph structure of the Top-Level Design Document (TLDD) because the DID for that document does not provide enough detail to be useful as a top-level design description for reusable parts. Appendix I summarizes the modifications made to this DID to tailor it for the description of the detailed design of reusable missile software parts.

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3.3.7.1.9.6.10.9.5 PROCESS CONTROL 1833
3.3.7.1.9.6.10.9.6 PROCESSING 1833
3.3.7.1.9.6.10.9.7 UTILIZATION OF OTHER ELEMENTS 1833
3.3.7.1.9.6.10.9.8 LIMITATIONS 1834
3.3.7.1.9.6.10.10 SET_NEXT UNIT DESIGN 1834
3.3.7.1.9.6.10.10.1 REQUIREMENTS ALLOCATION 1834
3.3.7.1.9.6.10.10.2 LOCAL ENTITIES DESIGN 1834
3.3.7.1.9.6.10.10.3 INPUT/OUTPUT 1834
3.3.7.1.9.6.10.10.4 LOCAL DATA 1834
3.3.7.1.9.6.10.10.5 PROCESS CONTROL 1834
3.3.7.1.9.6.10.10.6 PROCESSING 1835
3.3.7.1.9.6.10.10.7 UTILIZATION OF OTHER ELEMENTS 1835
3.3.7.1.9.6.10.10.8 LIMITATIONS 1835
3.3.7.1.9.7 BOUNDED_STACK PACKAGE DESIGN (CATALOG #P335-0) 1835
3.3.7.1.9.7.1 REQUIREMENTS ALLOCATION 1835
3.3.7.1.9.7.2 LOCAL ENTITIES DESIGN 1836
3.3.7.1.9.7.3 INPUT/OUTPUT 1836
3.3.7.1.9.7.4 LOCAL DATA 1836
3.3.7.1.9.7.5 PROCESS CONTROL 1836
3.3.7.1.9.7.6 PROCESSING 1836
3.3.7.1.9.7.7 UTILIZATION OF OTHER ELEMENTS 1837
3.3.7.1.9.7.8 LIMITATIONS 1838
3.3.7.1.9.7.9 LLCSC DESIGN 1838
3.3.7.1.9.7.10 UNIT DESIGN 1838

3.3.7.1.9.7.10.1 CLEAR_STACK UNIT DESIGN 1838
3.3.7.1.9.7.10.1.1 REQUIREMENTS ALLOCATION 1838
3.3.7.1.9.7.10.1.2 LOCAL ENTITIES DESIGN 1838
3.3.7.1.9.7.10.1.3 INPUT/OUTPUT 1838
3.3.7.1.9.7.10.1.4 LOCAL DATA 1838
3.3.7.1.9.7.10.1.5 PROCESS CONTROL 1839
3.3.7.1.9.7.10.1.6 PROCESSING 1839
3.3.7.1.9.7.10.1.7 UTILIZATION OF OTHER ELEMENTS 1839
3.3.7.1.9.7.10.1.8 LIMITATIONS 1839
3.3.7.1.9.7.10.2 ADD_ELEMENT UNIT DESIGN 1840
3.3.7.1.9.7.10.2.1 REQUIREMENTS ALLOCATION 1840
3.3.7.1.9.7.10.2.2 LOCAL ENTITIES DESIGN 1840
3.3.7.1.9.7.10.2.3 INPUT/OUTPUT 1840
3.3.7.1.9.7.10.2.4 LOCAL DATA 1840
3.3.7.1.9.7.10.2.5 PROCESS CONTROL 1840
3.3.7.1.9.7.10.2.6 PROCESSING 1840
3.3.7.1.9.7.10.2.7 UTILIZATION OF OTHER ELEMENTS 1841
3.3.7.1.9.7.10.2.8 LIMITATIONS 1842
3.3.7.1.9.7.10.3 RETRIEVE_ELEMENT UNIT DESIGN 1842
3.3.7.1.9.7.10.3.1 REQUIREMENTS ALLOCATION 1842
3.3.7.1.9.7.10.3.2 LOCAL ENTITIES DESIGN 1842
3.3.7.1.9.7.10.3.3 INPUT/OUTPUT 1843
3.3.7.1.9.7.10.3.4 LOCAL DATA 1843
3.3.7.1.9.7.10.3.5 PROCESS CONTROL 1843
3.3.7.1.9.7.10.3.6 PROCESSING 1843
3.3.7.1.9.7.10.3.7 UTILIZATION OF OTHER ELEMENTS 1844
3.3.7.1.9.7.10.3.8 LIMITATIONS 1845
3.3.7.1.9.7.10.4 PEEK UNIT DESIGN 1845
3.3.7.1.9.7.10.4.1 REQUIREMENTS ALLOCATION 1845
3.3.7.1.9.7.10.4.2 LOCAL ENTITIES DESIGN 1845
3.3.7.1.9.7.10.4.3 INPUT/OUTPUT 1845
3.3.7.1.9.7.10.4.4 LOCAL DATA 1846
3.3.7.1.9.7.10.4.5 PROCESS CONTROL 1846
3.3.7.1.9.7.10.4.6 PROCESSING 1846
3.3.7.1.9.7.10.4.7 UTILIZATION OF OTHER ELEMENTS 1846
3.3.7.1.9.7.10.4.8 LIMITATIONS 1848
3.3.7.1.9.7.10.5 STACK_STATUS UNIT DESIGN 1848
3.3.7.1.9.7.10.5.1 REQUIREMENTS ALLOCATION 1848
3.3.7.1.9.7.10.5.2 LOCAL ENTITIES DESIGN 1848
3.3.7.1.9.7.10.5.3 INPUT/OUTPUT 1848
3.3.7.1.9.7.10.5.4 LOCAL DATA 1848
3.3.7.1.9.7.10.5.5 PROCESS CONTROL 1849
3.3.7.1.9.7.10.5.6 PROCESSING 1849
3.3.7.1.9.7.10.5.7 UTILIZATION OF OTHER ELEMENTS 1849
3.3.7.1.9.7.10.5.8 LIMITATIONS 1850
3.3.7.1.9.7.10.6 STACK_LENGTH UNIT DESIGN 1850
3.3.7.1.9.7.10.6.1 REQUIREMENTS ALLOCATION 1850
3.3.7.1.9.7.10.6.2 LOCAL ENTITIES DESIGN 1850
3.3.7.1.9.7.10.6.3 INPUT/OUTPUT 1851
3.3.7.1.9.7.10.6.4 LOCAL DATA 1851
3.3.7.1.9.7.10.6.5 PROCESS CONTROL 1851
3.3.7.1.9.7.10.6.6 PROCESSING 1851
3.3.7.1.9.7.10.6.7 UTILIZATION OF OTHER ELEMENTS 1851
3.3.7.1.9.7.10.6.8 LIMITATIONS 1852
3.3.7.1.9.8 UNBOUNDED_STACK PACKAGE DESIGN (CATALOG #P336-0) 1852
3.3.7.1.9.8.1 REQUIREMENTS ALLOCATION 1852

3.3.7.1.9.8.2 LOCAL ENTITIES DESIGN 1852
3.3.7.1.9.8.3 INPUT/OUTPUT 1853
3.3.7.1.9.8.4 LOCAL DATA 1854
3.3.7.1.9.8.5 PROCESS CONTROL 1854
3.3.7.1.9.8.6 PROCESSING 1854
3.3.7.1.9.8.7 UTILIZATION OF OTHER ELEMENTS 1855
3.3.7.1.9.8.8 LIMITATIONS 1857
3.3.7.1.9.8.9 LLCSC DESIGN 1857
3.3.7.1.9.8.10 UNIT DESIGN 1857
3.3.7.1.9.8.10.1 INITIALIZE UNIT DESIGN 1857
3.3.7.1.9.8.10.1.1 REQUIREMENTS ALLOCATION 1857
3.3.7.1.9.8.10.1.2 LOCAL ENTITIES DESIGN 1857
3.3.7.1.9.8.10.1.3 INPUT/OUTPUT 1857
3.3.7.1.9.8.10.1.4 LOCAL DATA 1858
3.3.7.1.9.8.10.1.5 PROCESS CONTROL 1858
3.3.7.1.9.8.10.1.6 PROCESSING 1858
3.3.7.1.9.8.10.1.7 UTILIZATION OF OTHER ELEMENTS 1859
3.3.7.1.9.8.10.1.8 LIMITATIONS 1859
3.3.7.1.9.8.10.2 CLEAR_STACK UNIT DESIGN 1860
3.3.7.1.9.8.10.2.1 REQUIREMENTS ALLOCATION 1860
3.3.7.1.9.8.10.2.2 LOCAL ENTITIES DESIGN 1860
3.3.7.1.9.8.10.2.3 INPUT/OUTPUT 1860
3.3.7.1.9.8.10.2.4 LOCAL DATA 1860
3.3.7.1.9.8.10.2.5 PROCESS CONTROL 1861
3.3.7.1.9.8.10.2.6 PROCESSING 1861
3.3.7.1.9.8.10.2.7 UTILIZATION OF OTHER ELEMENTS 1861
3.3.7.1.9.8.10.2.8 LIMITATIONS 1862
3.3.7.1.9.8.10.3 FREE_MEMORY UNIT DESIGN 1863
3.3.7.1.9.8.10.3.1 REQUIREMENTS ALLOCATION 1863
3.3.7.1.9.8.10.3.2 LOCAL ENTITIES DESIGN 1863
3.3.7.1.9.8.10.3.3 INPUT/OUTPUT 1863
3.3.7.1.9.8.10.3.4 LOCAL DATA 1863
3.3.7.1.9.8.10.3.5 PROCESS CONTROL 1863
3.3.7.1.9.8.10.3.6 PROCESSING 1863
3.3.7.1.9.8.10.3.7 UTILIZATION OF OTHER ELEMENTS 1864
3.3.7.1.9.8.10.3.8 LIMITATIONS 1864
3.3.7.1.9.8.10.4 ADD_ELEMENT UNIT DESIGN 1865
3.3.7.1.9.8.10.4.1 REQUIREMENTS ALLOCATION 1865
3.3.7.1.9.8.10.4.2 LOCAL ENTITIES DESIGN 1865
3.3.7.1.9.8.10.4.3 INPUT/OUTPUT 1865
3.3.7.1.9.8.10.4.4 LOCAL DATA 1865
3.3.7.1.9.8.10.4.5 PROCESS CONTROL 1865
3.3.7.1.9.8.10.4.6 PROCESSING 1865
3.3.7.1.9.8.10.4.7 UTILIZATION OF OTHER ELEMENTS 1866
3.3.7.1.9.8.10.4.8 LIMITATIONS 1867
3.3.7.1.9.8.10.5 RETRIEVE_ELEMENT UNIT DESIGN 1867
3.3.7.1.9.8.10.5.1 REQUIREMENTS ALLOCATION 1868
3.3.7.1.9.8.10.5.2 LOCAL ENTITIES DESIGN 1868
3.3.7.1.9.8.10.5.3 INPUT/OUTPUT 1868
3.3.7.1.9.8.10.5.4 LOCAL DATA 1868
3.3.7.1.9.8.10.5.5 PROCESS CONTROL 1868
3.3.7.1.9.8.10.5.6 PROCESSING 1868
3.3.7.1.9.8.10.5.7 UTILIZATION OF OTHER ELEMENTS 1869
3.3.7.1.9.8.10.5.8 LIMITATIONS 1870
3.3.7.1.9.8.10.6 PEEK UNIT DESIGN 1870
3.3.7.1.9.8.10.6.1 REQUIREMENTS ALLOCATION 1871
3.3.7.1.9.8.10.6.2 LOCAL ENTITIES DESIGN 1871

3.3.7.1.9.8.10.6.3 INPUT/OUTPUT 1871
3.3.7.1.9.8.10.6.4 LOCAL DATA 1871
3.3.7.1.9.8.10.6.5 PROCESS CONTROL 1871
3.3.7.1.9.8.10.6.6 PROCESSING 1871
3.3.7.1.9.8.10.6.7 UTILIZATION OF OTHER ELEMENTS 1872
3.3.7.1.9.8.10.6.8 LIMITATIONS 1873
3.3.7.1.9.8.10.7 STACK_STATUS UNIT DESIGN 1873
3.3.7.1.9.8.10.7.1 REQUIREMENTS ALLOCATION 1873
3.3.7.1.9.8.10.7.2 LOCAL ENTITIES DESIGN 1873
3.3.7.1.9.8.10.7.3 INPUT/OUTPUT 1873
3.3.7.1.9.8.10.7.4 LOCAL DATA 1874
3.3.7.1.9.8.10.7.5 PROCESS CONTROL 1874
3.3.7.1.9.8.10.7.6 PROCESSING 1874
3.3.7.1.9.8.10.7.7 UTILIZATION OF OTHER ELEMENTS 1875
3.3.7.1.9.8.10.7.8 LIMITATIONS 1875
3.3.7.1.9.8.10.8 STACK_LENGTH UNIT DESIGN 1875
3.3.7.1.9.8.10.8.1 REQUIREMENTS ALLOCATION 1875
3.3.7.1.9.8.10.8.2 LOCAL ENTITIES DESIGN 1875
3.3.7.1.9.8.10.8.3 INPUT/OUTPUT 1876
3.3.7.1.9.8.10.8.4 LOCAL DATA 1876
3.3.7.1.9.8.10.8.5 PROCESS CONTROL 1876
3.3.7.1.9.8.10.8.6 PROCESSING 1876
3.3.7.1.9.8.10.8.7 UTILIZATION OF OTHER ELEMENTS 1876
3.3.7.1.9.8.10.8.8 LIMITATIONS 1877
3.3.7.1.9.8.10.9 DOT_NEXT UNIT DESIGN 1877
3.3.7.1.9.8.10.9.1 REQUIREMENTS ALLOCATION 1877
3.3.7.1.9.8.10.9.2 LOCAL ENTITIES DESIGN 1877
3.3.7.1.9.8.10.9.3 INPUT/OUTPUT 1878
3.3.7.1.9.8.10.9.4 LOCAL DATA 1878
3.3.7.1.9.8.10.9.5 PROCESS CONTROL 1878
3.3.7.1.9.8.10.9.6 PROCESSING 1878
3.3.7.1.9.8.10.9.7 UTILIZATION OF OTHER ELEMENTS 1878
3.3.7.1.9.8.10.9.8 LIMITATIONS 1879
3.3.7.1.9.8.10.10 SET_NEXT UNIT DESIGN 1879
3.3.7.1.9.8.10.10.1 REQUIREMENTS ALLOCATION 1879
3.3.7.1.9.8.10.10.2 LOCAL ENTITIES DESIGN 1879
3.3.7.1.9.8.10.10.3 INPUT/OUTPUT 1879
3.3.7.1.9.8.10.10.4 LOCAL DATA 1879
3.3.7.1.9.8.10.10.5 PROCESS CONTROL 1879
3.3.7.1.9.8.10.10.6 PROCESSING 1879
3.3.7.1.9.8.10.10.7 UTILIZATION OF OTHER ELEMENTS 1880
3.3.7.1.9.8.10.10.8 LIMITATIONS 1880
3.3.7.1.10 UNIT DESIGN 1880

3.3.8 GENERAL UTILITIES 1915

3.3.8.1 GENERAL_UTILITIES TLCSC P361 (CATALOG #P267-0) 1917
3.3.8.1.1 REQUIREMENTS ALLOCATION 1917
3.3.8.1.2 LOCAL ENTITIES DESIGN 1917
3.3.8.1.3 INPUT/OUTPUT 1917
3.3.8.1.4 LOCAL DATA 1917
3.3.8.1.5 PROCESS CONTROL 1917
3.3.8.1.6 PROCESSING 1917
3.3.8.1.7 UTILIZATION OF OTHER ELEMENTS 1917
3.3.8.1.8 LIMITATIONS 1917
3.3.8.1.9 LLCSC DESIGN 1918
3.3.8.1.10 UNIT DESIGN 1918

3.3.8.1.10.1 INSTRUCTION_SET_TEST UNIT DESIGN (CATALOG #P268-0) 1918
3.3.8.1.10.1.1 REQUIREMENTS ALLOCATION 1918
3.3.8.1.10.1.2 LOCAL ENTITIES DESIGN 1918
3.3.8.1.10.1.3 INPUT/OUTPUT 1918
3.3.8.1.10.1.4 LOCAL DATA 1919
3.3.8.1.10.1.5 PROCESS CONTROL 1919
3.3.8.1.10.1.6 PROCESSING 1919
3.3.8.1.10.1.7 UTILIZATION OF OTHER ELEMENTS 1919
3.3.8.1.10.1.8 LIMITATIONS 1919

3.3.8.2 COMMUNICATION_PARTS TLCSC P602 (CATALOG #P691-0) 1923
3.3.8.2.1 REQUIREMENTS ALLOCATION 1923
3.3.8.2.2 LOCAL ENTITIES DESIGN 1923
3.3.8.2.3 INPUT/OUTPUT 1923
3.3.8.2.4 LOCAL DATA 1923
3.3.8.2.5 PROCESS CONTROL 1923
3.3.8.2.6 PROCESSING 1923
3.3.8.2.7 UTILIZATION OF OTHER ELEMENTS 1923
3.3.8.2.8 LIMITATIONS 1923
3.3.8.2.9 LLCSC DESIGN 1924
3.3.8.2.9.1 UPDATE_EXCLUSION PACKAGE DESIGN (CATALOG #P692-0) 1924
3.3.8.2.9.1.1 REQUIREMENTS ALLOCATION 1924
3.3.8.2.9.1.2 LOCAL ENTITIES DESIGN 1924
3.3.8.2.9.1.3 INPUT/OUTPUT 1924
3.3.8.2.9.1.4 LOCAL DATA 1925
3.3.8.2.9.1.5 PROCESS CONTROL 1925
3.3.8.2.9.1.6 PROCESSING 1925
3.3.8.2.9.1.7 UTILIZATION OF OTHER ELEMENTS 1927
3.3.8.2.9.1.8 LIMITATIONS 1927
3.3.8.2.9.1.9 LLCSC DESIGN 1928
3.3.8.2.9.1.10 UNIT DESIGN 1928
3.3.8.2.10 UNIT DESIGN 1928

3.3.9 EQUIPMENT INTERFACES 1933

3.3.9.1 CLOCK_HANDLER TLCSC P634 (CATALOG #P270-0) 1935
3.3.9.1.1 REQUIREMENTS ALLOCATION 1935
3.3.9.1.2 LOCAL ENTITIES DESIGN 1935
3.3.9.1.3 INPUT/OUTPUT 1935
3.3.9.1.4 LOCAL DATA 1935
3.3.9.1.5 PROCESS CONTROL 1936
3.3.9.1.6 PROCESSING 1936
3.3.9.1.7 UTILIZATION OF OTHER ELEMENTS 1936
3.3.9.1.8 LIMITATIONS 1937
3.3.9.1.9 LLCSC DESIGN 1937
3.3.9.1.10 UNIT DESIGN 1937
3.3.9.1.10.1 CURRENT_TIME (FUNCTION BODY) UNIT DESIGN 1937
3.3.9.1.10.1.1 REQUIREMENTS ALLOCATION 1937
3.3.9.1.10.1.2 LOCAL ENTITIES DESIGN 1937
3.3.9.1.10.1.3 INPUT/OUTPUT 1937
3.3.9.1.10.1.4 LOCAL DATA 1937
3.3.9.1.10.1.5 PROCESS CONTROL 1937
3.3.9.1.10.1.6 PROCESSING 1938
3.3.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS 1938
3.3.9.1.10.1.8 LIMITATIONS 1939

3.3.9.1.10.2 CONVERTED_TIME (FUNCTION BODY) UNIT DESIGN 1939
3.3.9.1.10.2.1 REQUIREMENTS ALLOCATION 1939
3.3.9.1.10.2.2 LOCAL ENTITIES DESIGN 1939
3.3.9.1.10.2.3 INPUT/OUTPUT 1939
3.3.9.1.10.2.4 LOCAL DATA 1939
3.3.9.1.10.2.5 PROCESS CONTROL 1940
3.3.9.1.10.2.6 PROCESSING 1940
3.3.9.1.10.2.7 UTILIZATION OF OTHER ELEMENTS 1940
3.3.9.1.10.2.8 LIMITATIONS 1941
3.3.9.1.10.3 RESET_CLOCK (PROCEDURE BODY) UNIT DESIGN 1941
3.3.9.1.10.3.1 REQUIREMENTS ALLOCATION 1941
3.3.9.1.10.3.2 LOCAL ENTITIES DESIGN 1941
3.3.9.1.10.3.3 INPUT/OUTPUT 1941
3.3.9.1.10.3.4 LOCAL DATA 1941
3.3.9.1.10.3.5 PROCESS CONTROL 1941
3.3.9.1.10.3.6 PROCESSING 1941
3.3.9.1.10.3.7 UTILIZATION OF OTHER ELEMENTS 1942
3.3.9.1.10.3.8 LIMITATIONS 1942
3.3.9.1.10.4 SYNCHRONIZE_CLOCK (PROCEDURE BODY) UNIT DESIGN 1943
3.3.9.1.10.4.1 REQUIREMENTS ALLOCATION 1943
3.3.9.1.10.4.2 LOCAL ENTITIES DESIGN 1943
3.3.9.1.10.4.3 INPUT/OUTPUT 1943
3.3.9.1.10.4.4 LOCAL DATA 1943
3.3.9.1.10.4.5 PROCESS CONTROL 1943
3.3.9.1.10.4.6 PROCESSING 1943
3.3.9.1.10.4.7 UTILIZATION OF OTHER ELEMENTS 1944
3.3.9.1.10.4.8 LIMITATIONS 1944
3.3.9.1.10.5 ELAPSED_TIME (FUNCTION BODY) UNIT DESIGN 1944
3.3.9.1.10.5.1 REQUIREMENTS ALLOCATION 1944
3.3.9.1.10.5.2 LOCAL ENTITIES DESIGN 1945
3.3.9.1.10.5.3 INPUT/OUTPUT 1945
3.3.9.1.10.5.4 LOCAL DATA 1945
3.3.9.1.10.5.5 PROCESS CONTROL 1945
3.3.9.1.10.5.6 PROCESSING 1945
3.3.9.1.10.5.7 UTILIZATION OF OTHER ELEMENTS 1946
3.3.9.1.10.5.8 LIMITATIONS 1946

4 (NOT USED) 1951

5 (NOT USED) 1953

6 NOTES 1955

APPENDIX I MODIFICATIONS TO DI-MCCR-80031

I.1 REQUIREMENTS FOR DOCUMENTING DESIGN OF REUSABLE PARTS I-1
I.1.1 PROBLEMS IN USING DI-MCCR-80031 . . . . . I-1
I.1.2 DESIGN CODE HEADER FOR DETAILED DESIGN I-1

SOFTWARE DETAILED DESIGN DOCUMENT FOR THE MISSILE SOFTWARE PARTS OF THE COMMON ADA MISSILE PACKAGES (CAMP) PROJECT

1 SCOPE

1.1 IDENTIFICATION

This Software Detailed Design Document describes the detailed design for the CSCI identified as the Common Ada Missile Packages (CAMP) Missile Software Parts.

The CAMP-1 program was a twelve-month feasibility study which the McDonnell Douglas Astronautics Company performed under contract to the U.S. Air Force Armament Laboratory (AFATL). This project had two primary objectives:

(1) To determine the feasibility of developing reusable missile software components written in Ada; and,

(2) To determine the feasibility of developing an automated or semi-automated missile software generation system.

The CAMP-2 program was a twenty-four-month study which the McDonnell Douglas Astronautics Company performed under contract to the U.S. Air Force Armament Laboratory (AFATL). The primary objectives of this project were:

(1) Prepare the detailed design for those parts receiving top-level design under the CAMP-1 program.

(2) Show that reusable software parts can result in significant productivity and quality improvements.

(3) Implement an 11th missile application using CAMP parts.

The detailed design of this CSCI meets the requirements which resulted from the domain analysis performed during CAMP-1. Although software parts contained in this CSCI are used by the software generator, there are no direct software or hardware interfaces between the two CSCI's.

1.2 PURPOSE

The Missile Software Parts constitute a set of common software identifed under the domain analysis of the CAMP study. These software parts are grouped into Top-Level Computer Software Components (TLCSC's) and are divided into the categories listed below.

a. Data Types - TLCSC's which provide data types used in other TLCSC's or in a user application:

- o Basic Data Types TLCSC
- o Kalman Filter Data Types TLCSC
- o Autopilot Data Types TLCSC

b. Navigation - TLCSC's which provide the basic functionality of a navigation sybsystem.

- o Common Navigation Parts TLCSC
- o North Pointing Navigation Parts TLCSC
- o Wander Angle Navigation Parts TLCSC
- o Direction Cosine Matrix Operations TLCSC

c. Kalman Filter - TLCSC's which provide common Kalman Filter functions.

- o Common Kalman Filter TLCSC
- o Compact-H Kalman Filter TLCSC
- o Complicated-H Kalman Filter TLCSC

d. Guidance and Control - TLCSC's which provide the basic functionality of a guidance and control subsystem.

- o Waypoint Steering TLCSC
- o Autopilot TLCSC

e. Nonguidance Control - TLCSC's which provide the basic functionality of a control subsystem for operations outside of the guidance area.

- o Air Data TLCSC
- o Fuel Control TLCSC

f. Mathematical - TLCSC's which provide a variety of useful mathematical functions such as coordinate and matrix algebra, trigonometric, and signal processing functions.

- o Coordinate Algebra TLCSC
- o Matrix Algebra TLCSC
- o Geometric TLCSC
- o Trigonometry TLCSC
- o Unit Conversion TLCSC
- o External Form Conversion TLCSC
- o Signal Processing TLCSC
- o General Purpose Math TLCSC
- o Polynomial Math TLCSC
- o Quaternion Math TLCSC

g. Abstract Mechanisms - TLCSC's which provide abstract data structures and processes.

- o Data Structures TLCSC

h. General Utilities - TLCSC's which provide other functions needed for missile or other weapons system operation.

- o General Utilities TLCSC
- o Communication Parts TLCSC

i. Equipment Interfaces - TLCSC's which provide functions needed to interface with the hardware:

- o Clock Handler TLCSC

The following lists the TLCSC's identified in the CAMP Top-Level Design Document for which no detailed design exists. Detailed design is not required for these parts either because they deal exclusively with data constants or because they are schematic parts.

a. Data constants - TLCSC's which provide data constants used in a typical application:

- o WGS-72 Engineering TLCSC
- o WGS-72 Metric TLCSC
- o WGS-72 Unitless TLCSC
- o Universal Constants TLCSC
- o Conversion Factors TLCSC

b. Equipment Interfaces - TLCSC's which provide standard interfaces to specific hardware components or to general classes of hardware.

- o Radar Altimeter Interface TLCSC's
- o Data Bus Handler TLCSC

c. Abstract Mechanisms - TLCSC's which provide abstract data structures and processes.

- o Abstract Processes TLCSC (schematic part)

d. Process Management - TLCSC's which provide control of concurrent processes and communication.

- o Asynchronous Control TLCSC (schematic part)

1.3 INTRODUCTION

This Software Detailed Design Document (DDD) provides the detailed design requirements of common missile software parts as stated in the Software Requirements Specification developed under Contract F08635-84-C-0280 of the CAMP Program.

The following figure shows the organization of TLCSC's requiring detailed design and the structure for the major section of this document, Section 3.3 (Detailed Design).

DATA TYPES 3.3.1
Basic Data Types TLCSC 3.3.1.1
Kalman Filter Data Types TLCSC 3.3.1.2
Autopilot Data Types TLCSC 3.3.1.3

NAVIGATION 3.3.2
Common Navigation Parts TLCSC 3.3.2.1
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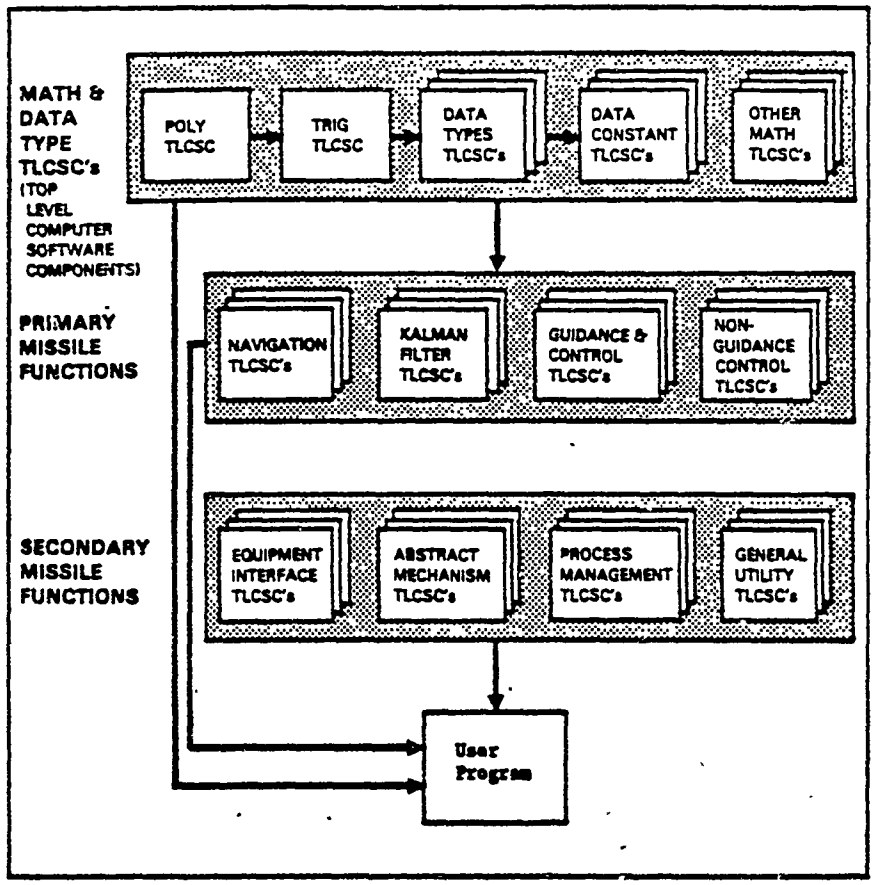
ORGANIZATION OF CAMP TLCSC'S

The following figure illustrates the top-level architecture and dependencies of the TLCSC's. The top section of this figure shows the mathematical and data type packages. These TLCSC's provide the data types and mathematical operations to a user program or to other TLCSC's within the design, as shown by the arrows. At the center of the figure are the primary missile TLCSC's: Navigation, Kalman Filter, Guidance and Control, and Non-guidance Control. These TLCSC's require data types and mathematical operators from other TLCSC's and provide operations to the user program. On the right of the figure are secondary missile TLCSC's. These also provide operations to a user program, as illustrated by the arrows.



ARCHITECTURAL DEPENDENCIES OF TLCSC'S

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2 APPLICABLE DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

The following documents of the exact issue shown form a part of the specification to the extent described herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered a superseding requirement.

STANDARDS

MILITARY

MIL-STD-490	Specification Practices (4 June 1985)
MIL-STD-1815A	Reference Manual for the Ada Programming Language (17 February 1983)
DOD-STD-2167	Defense System Software Development (4 June 1985)

OTHER PUBLICATIONS

CAMP Final Technical Report, Volume 1, 2, & 3 (4 September 1985)

Ada Missile Parts Engineering Expert System Software Requirements Specification (4 September 1985)

Ada Missile Parts Engineering Expert System Software Top-Level Design Document (4 September 1985)

Ada Missile Parts Engineering Expert System Software Detailed Design Document (Draft 30 August 1986)

CAMP Missile Software Parts Requirements Specification (4 September 1985)

CAMP Missile Software Parts Software Top-Level Design Document (4 September 1985)

World Geodetic Survey, 1972 (WGS72). Defense Mapping Agency, DMA 72-1

2.2 NON-GOVERNMENT DOCUMENTS

The following documents of the exact issue shown form a part of the specification to the extend specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

STANDARDS

Ada Design Language Reference Manual ((c) 1983, McDonnell Douglas Astronautics Company)

OTHER PUBLICATIONS:

VAX Ada Programmer's Run-Time Reference Manual (February, 1985, Digital Equipment Corporation)

VAX Ada Language Reference Manual (February, 1985, Digital Equipment Corporation)

3 REQUIREMENTS

3.1 INTERFACE DESIGN

There are no interfaces between this CSCI and other CSCI's or CI's. Interfaces between TLCSC's are described under Section 3.3 (Detailed Design).

3.2 GLOBAL DATA AND DATA TYPES

Global data and data types are provided by TLCSC's in the categories of data constants and data types. The specific global objects and types declared in these TLCSC's are discussed in sections 3.6.1 of the Software Top-Level Design Document (Data Constants) and 3.3.1 of this document (Data Types).

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3.3 DETAILED DESIGN

3.3.1 DATA TYPES

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3.3.1.1 BASIC DATA TYPES (BODY) TLCSC P621 (CATALOG #P1093-0)

This part, which is designed as an Ada package, defines simple data types and special operators for these data types.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.1.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R021.

3.3.1.1.2 LOCAL ENTITIES DESIGN

None.

3.3.1.1.3 INPUT/OUTPUT

None.

3.3.1.1.4 LOCAL DATA

None.

3.3.1.1.5 PROCESS CONTROL

Not applicable.

3.3.1.1.6 PROCESSING

The following describes the processing performed by this part:

```
with Conversion_Factors;
package body Basic_Data_Types is

   package CF renames Conversion_Factors;
   use Trig;

-- ----------------------------------------
-- --Define Operators for Basic Data Types-
-- ----------------------------------------

-- --Acceleration * Interval ==> Velocity

   function "*" (Left  :  Feet_per_Second_Squared;
                 Right : Seconds)
                return Feet_Per_Second is
      Temp : Feet_Per_Second;
   begin
      Temp := Feet_Per_Second (Seconds (Left) * Right);
      return Temp;
```

```
   end "*";

   function "*" (Left  :  Meters_per_Second_Squared;
                 Right : Seconds)
                return Meters_Per_Second is
      Temp : Meters_Per_Second;
   begin
      Temp := Meters_Per_Second (Seconds (Left) * Right);
      return Temp;
   end "*";

-- --Acceleration * Sin Cos Ratio ==> Acceleration

   function "*" (Left  : Feet_per_Second_Squared;
                 Right : Trig.Sin_Cos_Ratio) return Feet_per_Second_Squared is
   begin
      return Left * Feet_per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Meters_per_Second_Squared;
                 Right : Trig.Sin_Cos_Ratio)
                return Meters_per_Second_Squared is
   begin
      return Left * Meters_per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Gees;
                 Right : Trig.Sin_Cos_Ratio) return Gees is
   begin
      return Left * Gees (Right);
   end "*";

-- --Acceleration * Tan Ratio ==> Acceleration

   function "*" (Left  : Feet_per_Second_Squared;
                 Right : Trig.Tan_Ratio) return Feet_per_Second_Squared is
   begin
      return Left * Feet_per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Meters_per_Second_Squared;
                 Right : Trig.Tan_Ratio) return Meters_per_Second_Squared is
   begin
      return Left * Meters_per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Gees; Right : Trig.Tan_Ratio) return Gees is
   begin
      return Left * Gees (Right);
   end "*";


-- --Angular_Velocity * Angular_Velocity ==> Angular_Velocity Squared

   function "*" (Left  : Radians_per_Second;
                 Right : Radians_per_Second)
                return Radians_Squared_per_Second_Squared is
```

```
      Temp : Radians_per_Second;
   begin
      Temp := Left * Right;
      return Radians_Squared_per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Degrees_per_Second;
                 Right : Degrees_per_Second)
                return Degrees_Squared_per_Second_Squared is
      Temp : Degrees_per_Second;
   begin
      Temp := Left * Right;
      return Degrees_Squared_per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Semicircles_per_Second;
                 Right : Semicircles_per_Second)
                return Semicircles_Squared_per_Second_Squared is
      Temp : Semicircles_per_Second;
   begin
      Temp := Left * Right;
      return Semicircles_Squared_per_Second_Squared (Temp);
   end "*";

-- --Angular Velocity / Sin Cos Ratio ==> Angular Velocity

   function "/" (Left  : Radians_Per_Second;
                 Right : Trig.Sin_Cos_Ratio)
                return Radians_Per_Second is
   begin
      return Left / Radians_Per_Second (Right);
   end "/";

-- --Angular Velocity * Tan_Ratio ==> Angular Velocity

   function "*" (Left  : Radians_Per_Second;
                 Right : Trig.Tan_Ratio)
                return Radians_Per_Second is
   begin
      return Left * Radians_Per_Second (Right);
   end "*";

-- --Angular_Velocity * Time_Interval ==> Angle

   function "*" (Left  : Degrees_Per_Second;
                 Right : Seconds) return Trig.Degrees is
   begin
      return Trig.Degrees (Right * Seconds (Left));
   end "*";

   function "*" (Left  : Radians_Per_Second;
                 Right : Seconds) return Trig.Radians is
   begin
      return Trig.Radians (Right * Seconds (Left));
   end "*";

-- --Angular Velocity * Time Interval ==> Earth Position
```

```
   function "*" (Left  : Radians_Per_Second;
                 Right : Seconds)
                return Earth_Position_Radians is
   begin
      return Earth_Position_Radians (Seconds (Left) * Right);
   end "*";

-- --Angular_Velocity * Velocity ==> Acceleration

   function "*" (Left  : Radians_per_Second;
                 Right : Meters_Per_Second)
                return Meters_Per_Second_Squared is
      Temp : Meters_Per_Second;
   begin
      Temp := Meters_Per_Second (Left) * Right;
      return Meters_Per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Radians_per_Second;
                 Right : Feet_Per_Second)
                return Feet_Per_Second_Squared is
      Temp : Feet_Per_Second;
   begin
      Temp := Feet_Per_Second (Left) * Right;
      return Feet_Per_Second_Squared (Temp);
   end "*";


-- --Distance * 1/Distance ==> Sin_Cos_Ratio

   function "*" (Left  : Feet;
                 Right : Inverse_Feet) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Left * Feet (Right));
   end "*";

   function "*" (Left  : Meters;
                 Right : Inverse_Meters) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Left * Meters (Right));
   end "*";

-- --Distance * 1/Distance ==> Tan_Ratio

   function "*" (Left  : Feet;
                 Right : Inverse_Feet) return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left * Feet (Right));
   end "*";

   function "*" (Left  : Meters;
                 Right : Inverse_Meters) return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left * Meters (Right));
   end "*";
```

```
-- --Distance * INTEGER ==> Distance

   function "*" (Left  : Feet;   Right : INTEGER) return Feet is
   begin
      return Left * Feet (Right);
   end "*";

   function "*" (Left  : Meters; Right : INTEGER) return Meters is
   begin
      return Left * Meters (Right);
   end "*";

-- --Distance * Tan_Ratio => Distance

   function "*" (Left  : Feet;
                 Right : Trig.Tan_Ratio) return Feet is
   begin
      return Left * Feet (Right);
   end "*";

   function "*" (Left  : Meters;
                 Right : Trig.Tan_Ratio) return Meters is
   begin
      return Left * Meters (Right);
   end "*";

-- --Distance * Sin_Cos_Ratio ==> Distance

   function "*" (Left  : Feet;   Right : Trig.Sin_Cos_Ratio) return Feet is
   begin
      return Left * Feet (Right);
   end "*";

   function "*" (Left  : Meters; Right : Trig.Sin_Cos_Ratio) return Meters is
   begin
      return Left * Meters (Right);
   end "*";

-- --Distance * Velocity => Tan_Ratio;

   function "*" (Left  : Feet;
                 Right : Feet_Per_Second) return Trig.Tan_Ratio is
      Temp : Feet;
   begin
      Temp := Left * Feet (Right);
      return Trig.Tan_Ratio (Temp);
   end "*";

   function "*" (Left  : Meters;
                 Right : Meters_Per_Second) return Trig.Tan_Ratio is
      Temp : Meters;
   begin
      Temp := Left * Meters (Right);
      return Trig.Tan_Ratio (Temp);
   end "*";
```

```
-- --INTEGER * Sin_Cos_Ratio ==> Sin_Cos_Ratio

   function "*" (Left  : INTEGER;
                 Right : Trig.Sin_Cos_Ratio) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Left) * Right;
   end "*";


-- --Inverse_Distances * Tan_Ratio ==> Inverse_Distances

   function "*" (Left  : Inverse_Feet;
                 Right : Trig.Tan_Ratio) return Inverse_Feet is
   begin
      return Left * Inverse_Feet(Right);
   end "*";

   function "*" (Left  : Inverse_Meters;
                 Right : Trig.Tan_Ratio) return Inverse_Meters is
   begin
      return Left * Inverse_Meters(Right);
   end "*";


-- --Sin_Cos_Ratio * Angular Velocity ==> Angular Velocity

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Radians_Per_Second)
              return Radians_Per_Second is
   begin
      return Radians_Per_Second (Left) * Right;
   end "*";

-- --Sin_Cos_Ratio * Distance ==> Distance

   function "*" (Left  : Trig.Sin_Cos_Ratio; Right : Feet)   return Feet is
   begin
      return Feet (Left) * Right;
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio; Right : Meters) return Meters is
   begin
      return Meters (Left) * Right;
   end "*";

-- --Sin Cos Ratio * Tan Ratio => Tan Ratio
   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Tan_Ratio)
                return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left) * Right;
   end "*";

-- --Sin_Cos_Ratio * Velocity ==> Velocity

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Feet_Per_Second) return Feet_Per_Second is
```

```
   begin
      return Feet_Per_Second (Left) * Right;
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Meters_Per_Second) return Meters_Per_Second is
   begin
      return Meters_Per_Second (Left) * Right;
   end "*";


-- --Tan Ratio * Sin Cos Ratio => Tan Ratio
   function "*" (Left  : Trig.Tan_Ratio;
                 Right : Trig.Sin_Cos_Ratio)
                return Trig.Tan_Ratio is
   begin
      return Left * Trig.Tan_Ratio (Right);
   end "*";


-- --Velocity * Inverse_Distances ==> Angular_Velocity

   function "*" (Left  : Feet_per_Second;
                 Right : Inverse_Feet) return Radians_per_Second is
   begin
      return Radians_per_Second(Left) * Radians_per_Second(Right);
   end "*";

   function "*" (Left  : Meters_per_Second;
                 Right : Inverse_Meters) return Radians_per_Second is
   begin
      return Radians_per_Second(Left) * Radians_per_Second(Right);
   end "*";

-- --Velocity * Sin Cos Ratio ==> Velocity

   function "*" (Left  : Feet_per_Second;
                 Right : Trig.Sin_Cos_Ratio) return Feet_per_Second is
   begin
      return Left * Feet_per_Second (Right);
   end "*";

   function "*" (Left  : Meters_per_Second;
                 Right : Trig.Sin_Cos_Ratio) return Meters_per_Second  is
   begin
      return Left * Meters_per_Second (Right);
   end "*";

-- --Velocity * Velocity ==> Velocity Squared

   function "*" (Left  : Feet_per_Second;
                 Right : Feet_per_Second)
                return Feet_Squared_per_Second_Squared is
      Temp : Feet_per_Second;
   begin
      Temp := Left * Right;
      return Feet_Squared_per_Second_Squared (Temp);
```

```
   end "*";

   function "*" (Left  : Meters_per_Second;
                 Right : Meters_per_Second)
                return Meters_Squared_per_Second_Squared is
      Temp : Meters_per_Second;
   begin
      Temp := Left * Right;
      return Meters_Squared_per_Second_Squared (Temp);
   end "*";

-- --Velocity * Interval ==> Distance

   function "*" (Left  : Feet_per_Second;   Right : Seconds) return Feet is
      Temp : Feet_per_Second;
   begin
      Temp := Left * Feet_per_Second (Right);
      return Feet (Temp);
   end "*";

   function "*" (Left  : Meters_per_Second;
                 Right : Seconds) return Meters is
      Temp : Meters_per_Second;
   begin
      Temp := Left * Meters_per_Second (Right);
      return Meters (Temp);
   end "*";


-- --Times Operators to Support DCM TLCSC

   function "*" (Left  : Radians_Per_Second;
                 Right : Trig.Sin_Cos_Ratio) return Radians_Per_Second is
   begin
      return Left * Radians_Per_Second (Right);
   end "*";

   function "*" (Left  : Radians_Per_Second;
                 Right : Seconds) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Seconds (Left) * Right);
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Sin_Cos_Ratio) return Trig.Radians is
      Temp : Trig.Sin_Cos_Ratio;
   begin
      Temp := Left * Right;
      return Trig.Radians (Temp);
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Radians) return Trig.Sin_Cos_Ratio is
   begin
      return Left * Trig.Sin_Cos_Ratio (Right);
   end "*";
```

```
-- --Acceleration / Velocity ==> Angular Rate

   function "/" (Left  : Feet_per_Second_Squared;
                 Right : Feet_per_Second) return Radians_per_Second is
   begin
      return Radians_per_Second (Left / Feet_per_Second_Squared (Right));
   end "/";

   function "/" (Left  : Meters_per_Second_Squared;
                 Right : Meters_per_Second) return Radians_per_Second is
   begin
      return Radians_per_Second (Left / Meters_per_Second_Squared (Right));
   end "/";

   function "/" (Left  : Gees;
                 Right : Feet_per_Second) return Radians_per_Second is
   begin
      return Radians_per_Second ((CF.Feet_per_Sec2_per_Gee * Left)
                                 / Gees (Right));
   end "/";

   function "/" (Left  : Gees;
                 Right : Meters_per_Second) return Radians_per_Second is
   begin
      return Radians_per_Second (Gees (CF.Meters_per_Sec2_per_Gee) * Left
                                 / Gees (Right));
   end "/";

   function "/" (Left  : Feet_per_Second_Squared;
                 Right : Feet_per_Second) return Degrees_per_Second is
      Answer : Feet_per_Second_Squared;
   begin
      Answer := Left / Feet_per_Second_Squared (Right)
                * Feet_per_Second_Squared (CF.Degrees_per_Radian);
      return Degrees_per_Second (Answer);
   end "/";

   function "/" (Left  : Meters_per_Second_Squared;
                 Right : Meters_per_Second) return Degrees_per_Second is
      Answer : Meters_per_Second_Squared;
   begin
      Answer := Left / Meters_per_Second_Squared (Right)
                * Meters_per_Second_Squared (CF.Degrees_per_Radian);
      return Degrees_per_Second (Answer);
   end "/";

   function "/" (Left  : Gees;
                 Right : Feet_per_Second) return Degrees_per_Second is
      Answer : Gees;
   begin
      Answer := Gees (CF.Feet_per_Sec2_per_Gee) * Left
                / Gees (Right) * Gees (CF.Degrees_per_Radian);
      return Degrees_per_Second (Answer);
   end "/";

   function "/" (Left  : Gees;
```

```
                Right : Meters_per_Second) return Degrees_per_Second is
      Answer : Gees;
   begin
      Answer := Gees(CF.Meters_per_Sec2_per_Gee) * Left
                / Gees (Right) * Gees (CF.Degrees_per_Radian);
      return Degrees_per_Second (Answer);
   end "/";


-- --Angle / Seconds ==> Angular Rate

   function "/" (Left  : Trig.Radians;
                 Right : Seconds)
                return Radians_per_Second is
   begin
      return Radians_Per_Second (Seconds (Left) / Right);
   end "/";

   function "/" (Left  : Trig.Degrees;
                 Right : Seconds)
                return Degrees_Per_Second is
   begin
      return Degrees_Per_Second (Seconds (Left) / Right);
   end "/";

   function "/" (Left  : Trig.Semicircles;
                 Right : Seconds)
                return Semicircles_Per_Second is
   begin
      return Semicircles_Per_Second (Seconds (Left) / Right);
   end "/";


-- --Distance / Sin Cos Ratio ==> Distance

   function "/" (Left  : Feet;   Right : Trig.Sin_Cos_Ratio) return Feet is
   begin
      return Left / Feet (Right);
   end "/";

   function "/" (Left  : Meters; Right : Trig.Sin_Cos_Ratio) return Meters is
   begin
      return Left / Meters (Right);
   end "/";

-- --Distance / Tan Ratio ==> Distance

   function "/" (Left  : Feet;   Right : Trig.Tan_Ratio) return Feet is
   begin
      return Left / Feet (Right);
   end "/";

   function "/" (Left  : Meters; Right : Trig.Tan_Ratio) return Meters is
   begin
      return Left / Meters (Right);
   end "/";
```

```
-- --Distance / Distance ==> Sin_Cos_Ratio

   function "/" (Left  : Feet;
                 Right : Feet)   return Trig.Sin_Cos_Ratio is
      Temp : Feet;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";

   function "/" (Left  : Meters;
                 Right : Meters) return Trig.Sin_Cos_Ratio is
      Temp : Meters;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";


-- --Tan_Ratio := Sin_Cos_Ratio / Sin_Cos_Ratio

   function "/" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Sin_Cos_Ratio) return
                Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left) / Trig.Tan_Ratio (Right);
   end "/";

-- --Tan_Ratio := Sin_Cos_Ratio / Tan_Ratio

   function "/" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Tan_Ratio) return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left) / Right;
   end "/";


-- --Velocity / Velocity ==> Sin_Cos_Ratio

   function "/" (Left  : Feet_per_Second;
                 Right : Feet_per_Second) return Trig.Sin_Cos_Ratio is
      Temp : Feet_per_Second;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";

   function "/" (Left  : Meters_per_Second;
                 Right : Meters_per_Second)
                return Trig.Sin_Cos_Ratio is
      Temp : Meters_per_Second;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";

-- --Velocity / Velocity ==> Tan_Ratio
```

```
   function "/" (Left  : Feet_per_Second;
                 Right : Feet_Per_Second) return Trig.Tan_Ratio is
      Temp : Feet_Per_Second;
   begin
      Temp := Left / Right;
      return Trig.Tan_Ratio (Temp);
   end "/";

   function "/" (Left  : Meters_per_Second;
                 Right : Meters_Per_Second) return Trig.Tan_Ratio is
      Temp : Meters_Per_Second;
   begin
      Temp := Left / Right;
      return Trig.Tan_Ratio (Temp);
   end "/";

-- --Velocity / Time ==> Acceleration
   function "/" (Left  : Feet_per_Second;
                 Right : Seconds)
                return Feet_Per_Second_Squared is
   begin
      return Feet_Per_Second_Squared (Seconds (Left) / Right);
   end "/";

   function "/" (Left  : Meters_per_Second;
                 Right : Seconds)
                return Meters_Per_Second_Squared is
   begin
      return Meters_Per_Second_Squared (Seconds (Left) / Right);
   end "/";

-- --Velocity / Distance ==> Angular Rate

   function "/" (Left  : Feet_per_Second;
                 Right : Feet)
                return Radians_per_Second is
      Temp : Feet;
   begin
      Temp :=  Feet(Left) / Right;
      return Radians_Per_Second (Temp);
   end "/";

   function "/" (Left  : Meters_per_Second;
                 Right : Meters)
                return Radians_per_Second is
      Temp : Meters;
   begin
      Temp :=  Meters(Left) / Right;
      return Radians_Per_Second (Temp);
   end "/";


-- --Tan_Ratio := Tan_Ratio + Sin_Cos_Ratio

   function "+" (Left  : Trig.Tan_Ratio;
                 Right : Trig.Sin_Cos_Ratio) return Trig.Tan_Ratio is
```

```
   begin
      return Left + Trig.Tan_Ratio (Right);
   end "+";

end Basic_Data_Types;
```

3.3.1.1.7 UTILIZATION OF OTHER ELEMENTS

The following library units are with'd by this part:
1. SYSTEM (a predefined part of the Ada environment)
2. Standard_Trig (P689)
3. Conversion_Factors (P614)

3.3.1.1.8 LIMITATIONS

None.

3.3.1.1.9 LLCSC DESIGN

None.

3.3.1.1.10 UNIT DESIGN

None.

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```
with Conversion_Factors;
package body Basic_Data_Types is

   package Cf renames Conversion_Factors;
   use Trig;

-- ----------------------------------------
-- --Define Operators for Basic Data Types-
-- ----------------------------------------

-- --Acceleration * Interval ==> Velocity

   function "*" (Left  :  Feet_Per_Second_Squared;
                 Right : Seconds)
                return Feet_Per_Second is
      Temp : Feet_Per_Second;
   begin
      Temp := Feet_Per_Second (Seconds (Left) * Right);
      return Temp;
   end "*";

   function "*" (Left  :  Meters_Per_Second_Squared;
                 Right : Seconds)
                return Meters_Per_Second is
      Temp : Meters_Per_Second;
   begin
      Temp := Meters_Per_Second (Seconds (Left) * Right);
      return Temp;
   end "*";

-- --Acceleration * Sin Cos Ratio ==> Acceleration

   function "*" (Left  : Feet_Per_Second_Squared;
                 Right : Trig.Sin_Cos_Ratio) return Feet_Per_Second_Squared is
   begin
      return Left * Feet_Per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Meters_Per_Second_Squared;
                 Right : Trig.Sin_Cos_Ratio)
                return Meters_Per_Second_Squared is
   begin
      return Left * Meters_Per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Gees;
                 Right : Trig.Sin_Cos_Ratio) return Gees is
   begin
      return Left * Gees (Right);
   end "*";

-- --Acceleration * Tan Ratio ==> Acceleration

   function "*" (Left  : Feet_Per_Second_Squared;
                 Right : Trig.Tan_Ratio) return Feet_Per_Second_Squared is
   begin
      return Left * Feet_Per_Second_Squared (Right);
```

```
   end "*";

   function "*" (Left  : Meters_Per_Second_Squared;
                 Right : Trig.Tan_Ratio) return Meters_Per_Second_Squared is
   begin
      return Left * Meters_Per_Second_Squared (Right);
   end "*";

   function "*" (Left  : Gees; Right : Trig.Tan_Ratio) return Gees is
   begin
      return Left * Gees (Right);
   end "*";


-- --Angular_Velocity * Angular_Velocity ==> Angular_Velocity Squared

   function "*" (Left  : Radians_Per_Second;
                 Right : Radians_Per_Second)
                return Radians_Squared_Per_Second_Squared is
      Temp : Radians_Per_Second;
   begin
      Temp := Left * Right;
      return Radians_Squared_Per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Degrees_Per_Second;
                 Right : Degrees_Per_Second)
                return Degrees_Squared_Per_Second_Squared is
      Temp : Degrees_Per_Second;
   begin
      Temp := Left * Right;
      return Degrees_Squared_Per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Semicircles_Per_Second;
                 Right : Semicircles_Per_Second)
                return Semicircles_Squared_Per_Second_Squared is
      Temp : Semicircles_Per_Second;
   begin
      Temp := Left * Right;
      return Semicircles_Squared_Per_Second_Squared (Temp);
   end "*";

-- --Angular Velocity / Sin Cos Ratio ==> Angular Velocity

   function "/" (Left  : Radians_Per_Second;
                 Right : Trig.Sin_Cos_Ratio)
                return Radians_Per_Second is
   begin
      return Left / Radians_Per_Second (Right);
   end "/";

-- --Angular Velocity * Tan_Ratio ==> Angular Velocity

   function "*" (Left  : Radians_Per_Second;
                 Right : Trig.Tan_Ratio)
                return Radians_Per_Second is
```

```
   begin
      return Left * Radians_Per_Second (Right);
   end "*";

-- --Angular_Velocity * Time_Interval ==> Angle

   function "*" (Left  : Degrees_Per_Second;
                 Right : Seconds) return Trig.Degrees is
   begin
      return Trig.Degrees (Right * Seconds (Left));
   end "*";

   function "*" (Left  : Radians_Per_Second;
                 Right : Seconds) return Trig.Radians is
   begin
      return Trig.Radians (Right * Seconds (Left));
   end "*";

-- --Angular Velocity * Time Interval ==> Earth Position

   function "*" (Left  : Radians_Per_Second;
                 Right : Seconds)
                return Earth_Position_Radians is
   begin
      return Earth_Position_Radians (Seconds (Left) * Right);
   end "*";

-- --Angular_Velocity * Velocity ==> Acceleration

   function "*" (Left  : Radians_Per_Second;
                 Right : Meters_Per_Second)
                return Meters_Per_Second_Squared is
      Temp : Meters_Per_Second;
   begin
      Temp := Meters_Per_Second (Left) * Right;
      return Meters_Per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Radians_Per_Second;
                 Right : Feet_Per_Second)
                return Feet_Per_Second_Squared is
      Temp : Feet_Per_Second;
   begin
      Temp := Feet_Per_Second (Left) * Right;
      return Feet_Per_Second_Squared (Temp);
   end "*";


-- --Distance * 1/Distance ==> Sin_Cos_Ratio

   function "*" (Left  : Feet;
                 Right : Inverse_Feet) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Left * Feet (Right));
   end "*";

   function "*" (Left  : Meters;
```

```
                Right : Inverse_Meters) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Left * Meters (Right));
   end "*";

-- --Distance * 1/Distance ==> Tan_Ratio

   function "*" (Left  : Feet;
                 Right : Inverse_Feet) return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left * Feet (Right));
   end "*";

   function "*" (Left  : Meters;
                 Right : Inverse_Meters) return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left * Meters (Right));
   end "*";

-- --Distance * INTEGER ==> Distance

   function "*" (Left  : Feet;   Right : INTEGER) return Feet is
   begin
      return Left * Feet (Right);
   end "*";

   function "*" (Left  : Meters; Right : INTEGER) return Meters is
   begin
      return Left * Meters (Right);
   end "*";

-- --Distance * Tan_Ratio => Distance

   function "*" (Left  : Feet;
                 Right : Trig.Tan_Ratio) return Feet is
   begin
      return Left * Feet (Right);
   end "*";

   function "*" (Left  : Meters;
                 Right : Trig.Tan_Ratio) return Meters is
   begin
      return Left * Meters (Right);
   end "*";

-- --Distance * Sin_Cos_Ratio ==> Distance

   function "*" (Left  : Feet;   Right : Trig.Sin_Cos_Ratio) return Feet is
   begin
      return Left * Feet (Right);
   end "*";

   function "*" (Left  : Meters; Right : Trig.Sin_Cos_Ratio) return Meters is
   begin
      return Left * Meters (Right);
   end "*";
```

```
-- --Distance * Velocity => Tan_Ratio;

   function "*" (Left  : Feet;
                 Right : Feet_Per_Second) return Trig.Tan_Ratio is
      Temp : Feet;
   begin
      Temp := Left * Feet (Right);
      return Trig.Tan_Ratio (Temp);
   end "*";

   function "*" (Left  : Meters;
                 Right : Meters_Per_Second) return Trig.Tan_Ratio is
      Temp : Meters;
   begin
      Temp := Left * Meters (Right);
      return Trig.Tan_Ratio (Temp);
   end "*";


-- --INTEGER * Sin_Cos_Ratio ==> Sin_Cos_Ratio

   function "*" (Left  : INTEGER;
                 Right : Trig.Sin_Cos_Ratio) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Left) * Right;
   end "*";


-- --Inverse_Distances * Tan_Ratio ==> Inverse_Distances

   function "*" (Left  : Inverse_Feet;
                 Right : Trig.Tan_Ratio) return Inverse_Feet is
   begin
      return Left * Inverse_Feet(Right);
   end "*";

   function "*" (Left  : Inverse_Meters;
                 Right : Trig.Tan_Ratio) return Inverse_Meters is
   begin
      return Left * Inverse_Meters(Right);
   end "*";


-- --Sin_Cos_Ratio * Angular Velocity ==> Angular Velocity

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Radians_Per_Second)
                return Radians_Per_Second is
   begin
      return Radians_Per_Second (Left) * Right;
   end "*";

-- --Sin_Cos_Ratio * Distance ==> Distance

   function "*" (Left  : Trig.Sin_Cos_Ratio; Right : Feet)   return Feet is
   begin
      return Feet (Left) * Right;
```

```
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio; Right : Meters) return Meters is
   begin
      return Meters (Left) * Right;
   end "*";

-- --Sin Cos Ratio * Tan Ratio => Tan Ratio
   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Tan_Ratio)
                return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left) * Right;
   end "*";

-- --Sin_Cos_Ratio * Velocity ==> Velocity

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Feet_Per_Second) return Feet_Per_Second is
   begin
      return Feet_Per_Second (Left) * Right;
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Meters_Per_Second) return Meters_Per_Second is
   begin
      return Meters_Per_Second (Left) * Right;
   end "*";


-- --Tan Ratio * Sin Cos Ratio => Tan Ratio
   function "*" (Left  : Trig.Tan_Ratio;
                 Right : Trig.Sin_Cos_Ratio)
                return Trig.Tan_Ratio is
   begin
      return Left * Trig.Tan_Ratio (Right);
   end "*";


-- --Velocity * Inverse_Distances ==> Angular_Velocity

   function "*" (Left  : Feet_Per_Second;
                 Right : Inverse_Feet) return Radians_Per_Second is
   begin
      return Radians_Per_Second(Left) * Radians_Per_Second(Right);
   end "*";

   function "*" (Left  : Meters_Per_Second;
                 Right : Inverse_Meters) return Radians_Per_Second is
   begin
      return Radians_Per_Second(Left) * Radians_Per_Second(Right);
   end "*";

-- --Velocity * Sin Cos Ratio ==> Velocity

   function "*" (Left  : Feet_Per_Second;
                 Right : Trig.Sin_Cos_Ratio) return Feet_Per_Second is
```

```
   begin
      return Left * Feet_Per_Second (Right);
   end "*";

   function "*" (Left  : Meters_Per_Second;
                 Right : Trig.Sin_Cos_Ratio) return Meters_Per_Second  is
   begin
      return Left * Meters_Per_Second (Right);
   end "*";

-- --Velocity * Velocity ==> Velocity Squared

   function "*" (Left  : Feet_Per_Second;
                 Right : Feet_Per_Second)
                return Feet_Squared_Per_Second_Squared is
      Temp : Feet_Per_Second;
   begin
      Temp := Left * Right;
      return Feet_Squared_Per_Second_Squared (Temp);
   end "*";

   function "*" (Left  : Meters_Per_Second;
                 Right : Meters_Per_Second)
                return Meters_Squared_Per_Second_Squared is
      Temp : Meters_Per_Second;
   begin
      Temp := Left * Right;
      return Meters_Squared_Per_Second_Squared (Temp);
   end "*";

-- --Velocity * Interval ==> Distance

   function "*" (Left  : Feet_Per_Second;   Right : Seconds) return Feet is
      Temp : Feet_Per_Second;
   begin
      Temp := Left * Feet_Per_Second (Right);
      return Feet (Temp);
   end "*";

   function "*" (Left  : Meters_Per_Second;
                 Right : Seconds) return Meters is
      Temp : Meters_Per_Second;
   begin
      Temp := Left * Meters_Per_Second (Right);
      return Meters (Temp);
   end "*";


-- --Times Operators to Support DCM TLCSC

   function "*" (Left  : Radians_Per_Second;
                 Right : Trig.Sin_Cos_Ratio) return Radians_Per_Second is
   begin
      return Left * Radians_Per_Second (Right);
   end "*";

   function "*" (Left  : Radians_Per_Second;
```

```
                Right : Seconds) return Trig.Sin_Cos_Ratio is
   begin
      return Trig.Sin_Cos_Ratio (Seconds (Left) * Right);
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Sin_Cos_Ratio) return Trig.Radians is
      Temp : Trig.Sin_Cos_Ratio;
   begin
      Temp := Left * Right;
      return Trig.Radians (Temp);
   end "*";

   function "*" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Radians) return Trig.Sin_Cos_Ratio is
   begin
      return Left * Trig.Sin_Cos_Ratio (Right);
   end "*";


-- --Acceleration / Velocity ==> Angular Rate

   function "/" (Left  : Feet_Per_Second_Squared;
                 Right : Feet_Per_Second) return Radians_Per_Second is
   begin
      return Radians_Per_Second (Left / Feet_Per_Second_Squared (Right));
   end "/";

   function "/" (Left  : Meters_Per_Second_Squared;
                 Right : Meters_Per_Second) return Radians_Per_Second is
   begin
      return Radians_Per_Second (Left / Meters_Per_Second_Squared (Right));
   end "/";

   function "/" (Left  : Gees;
                 Right : Feet_Per_Second) return Radians_Per_Second is
   begin
      return Radians_Per_Second ((Cf.Feet_Per_Sec2_Per_Gee * Left)
                                 / Gees (Right));
   end "/";

   function "/" (Left  : Gees;
                 Right : Meters_Per_Second) return Radians_Per_Second is
   begin
      return Radians_Per_Second (Gees (Cf.Meters_Per_Sec2_Per_Gee) * Left
                                 / Gees (Right));
   end "/";

   function "/" (Left  : Feet_Per_Second_Squared;
                 Right : Feet_Per_Second) return Degrees_Per_Second is
      Answer : Feet_Per_Second_Squared;
   begin
      Answer := Left / Feet_Per_Second_Squared (Right)
                * Feet_Per_Second_Squared (Cf.Degrees_Per_Radian);
      return Degrees_Per_Second (Answer);
   end "/";
```

```
   function "/" (Left  : Meters_Per_Second_Squared;
                 Right : Meters_Per_Second) return Degrees_Per_Second is
      Answer : Meters_Per_Second_Squared;
   begin
      Answer := Left / Meters_Per_Second_Squared (Right)
                * Meters_Per_Second_Squared (Cf.Degrees_Per_Radian);
      return Degrees_Per_Second (Answer);
   end "/";

   function "/" (Left  : Gees;
                 Right : Feet_Per_Second) return Degrees_Per_Second is
      Answer : Gees;
   begin
      Answer := Gees (Cf.Feet_Per_Sec2_Per_Gee) * Left
                / Gees (Right) * Gees (Cf.Degrees_Per_Radian);
      return Degrees_Per_Second (Answer);
   end "/";

   function "/" (Left  : Gees;
                 Right : Meters_Per_Second) return Degrees_Per_Second is
      Answer : Gees;
   begin
      Answer := Gees(Cf.Meters_Per_Sec2_Per_Gee) * Left
                / Gees (Right) * Gees (Cf.Degrees_Per_Radian);
      return Degrees_Per_Second (Answer);
   end "/";

-- --Angle / Seconds ==> Angular Rate

   function "/" (Left  : Trig.Radians;
                 Right : Seconds)
                return Radians_Per_Second is
   begin
      return Radians_Per_Second (Seconds (Left) / Right);
   end "/";

   function "/" (Left  : Trig.Degrees;
                 Right : Seconds)
                return Degrees_Per_Second is
   begin
      return Degrees_Per_Second (Seconds (Left) / Right);
   end "/";

   function "/" (Left  : Trig.Semicircles;
                 Right : Seconds)
                return Semicircles_Per_Second is
   begin
      return Semicircles_Per_Second (Seconds (Left) / Right);
   end "/";

-- --Distance / Sin Cos Ratio ==> Distance

   function "/" (Left  : Feet;   Right : Trig.Sin_Cos_Ratio) return Feet is
   begin
      return Left / Feet (Right);
```

```
   end "/";

   function "/" (Left  : Meters; Right : Trig.Sin_Cos_Ratio) return Meters is
   begin
      return Left / Meters (Right);
   end "/";

-- --Distance / Tan Ratio ==> Distance

   function "/" (Left  : Feet;   Right : Trig.Tan_Ratio) return Feet is
   begin
      return Left / Feet (Right);
   end "/";

   function "/" (Left  : Meters; Right : Trig.Tan_Ratio) return Meters is
   begin
      return Left / Meters (Right);
   end "/";

-- --Distance / Distance ==> Sin_Cos_Ratio

   function "/" (Left  : Feet;
                 Right : Feet)   return Trig.Sin_Cos_Ratio is
      Temp : Feet;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";

   function "/" (Left  : Meters;
                 Right : Meters) return Trig.Sin_Cos_Ratio is
      Temp : Meters;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";


-- --Tan_Ratio := Sin_Cos_Ratio / Sin_Cos_Ratio

   function "/" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Sin_Cos_Ratio) return
                Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left) / Trig.Tan_Ratio (Right);
   end "/";

-- --Tan_Ratio := Sin_Cos_Ratio / Tan_Ratio

   function "/" (Left  : Trig.Sin_Cos_Ratio;
                 Right : Trig.Tan_Ratio) return Trig.Tan_Ratio is
   begin
      return Trig.Tan_Ratio (Left) / Right;
   end "/";


-- --Velocity / Velocity ==> Sin_Cos_Ratio
```

```
   function "/" (Left  : Feet_Per_Second;
                 Right : Feet_Per_Second) return Trig.Sin_Cos_Ratio is
      Temp : Feet_Per_Second;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";

   function "/" (Left  : Meters_Per_Second;
                 Right : Meters_Per_Second)
                return Trig.Sin_Cos_Ratio is
      Temp : Meters_Per_Second;
   begin
      Temp := Left / Right;
      return Trig.Sin_Cos_Ratio (Temp);
   end "/";

-- --Velocity / Velocity ==> Tan_Ratio

   function "/" (Left  : Feet_Per_Second;
                 Right : Feet_Per_Second) return Trig.Tan_Ratio is
      Temp : Feet_Per_Second;
   begin
      Temp := Left / Right;
      return Trig.Tan_Ratio (Temp);
   end "/";

   function "/" (Left  : Meters_Per_Second;
                 Right : Meters_Per_Second) return Trig.Tan_Ratio is
      Temp : Meters_Per_Second;
   begin
      Temp := Left / Right;
      return Trig.Tan_Ratio (Temp);
   end "/";

-- --Velocity / Time ==> Acceleration
   function "/" (Left  : Feet_Per_Second;
                 Right : Seconds)
                return Feet_Per_Second_Squared is
   begin
      return Feet_Per_Second_Squared (Seconds (Left) / Right);
   end "/";

   function "/" (Left  : Meters_Per_Second;
                 Right : Seconds)
                return Meters_Per_Second_Squared is
   begin
      return Meters_Per_Second_Squared (Seconds (Left) / Right);
   end "/";

-- --Velocity / Distance ==> Angular Rate

   function "/" (Left  : Feet_Per_Second;
                 Right : Feet)
                return Radians_Per_Second is
      Temp : Feet;
```

```
   begin
      Temp :=  Feet(Left) / Right;
      return Radians_Per_Second (Temp);
   end "/";

   function "/" (Left  : Meters_Per_Second;
                 Right : Meters)
                return Radians_Per_Second is
      Temp : Meters;
   begin
      Temp :=  Meters(Left) / Right;
      return Radians_Per_Second (Temp);
   end "/";


-- --Tan_Ratio := Tan_Ratio + Sin_Cos_Ratio

   function "+" (Left  : Trig.Tan_Ratio;
                 Right : Trig.Sin_Cos_Ratio) return Trig.Tan_Ratio is
   begin
      return Left + Trig.Tan_Ratio (Right);
   end "+";

end Basic_Data_Types;
```

3.3.1.2 KALMAN FILTER DATA TYPES (BODY) TLCSC P622 (CATALOG #P158-0)

This part, which is designed as an Ada generic package, defines data types (and operators on those data types) used in a Kalman Filter.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.1.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R023

3.3.1.2.2 LOCAL ENTITIES DESIGN

None.

3.3.1.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
State_Indices	Discrete type	Indexes the matrices which are a function of the _# of states
Measurement_ Indices	Discrete type	Indexes the matrices which are a function of the _# of measurements
Kalman_Filter _Elements	floating point type	Elements making up the matrices of the Kalman Filter

3.3.1.2.4 LOCAL DATA

None.

3.3.1.2.5 PROCESS CONTROL

Not applicable.

3.3.1.2.6 PROCESSING

The following describes the processing performed by this part:

package body Kalman_Filter_Data_Types is

```
-- ------------------------
-- --NAME:  Active_H_Vector
-- ------------------------

   function Active_H_Vector (Source : M_By_N_Statically_Sparse.Matrices;
                             Row    : Measurement_Indices)
                            return N_By_1.Vectors is
      Work_Vector : N_By_1.Vectors;
   begin
      for I in State_Indices loop
         Work_Vector (I) := Source (Row, I);
      end loop;
      return Work_Vector;
   end Active_H_Vector;

-- ----------------
-- --NAME:  Element
-- ----------------

   function Element (Source : N_By_N_Symmetric.Matrices;
                     Row    : State_Indices;
                     Column : State_Indices)
                    return Kalman_Filter_Elements is
   begin
      return Source (Row, Column);
   end Element;

-- ------------
-- --NAME:  Row
-- ------------

   function Row (Source : N_By_N_Symmetric.Matrices;
                 Row    : State_Indices)
                return N_By_1.Vectors is
      Work_Vector : N_By_1.Vectors;
   begin
      for I in State_Indices loop
         Work_Vector (I) := Source (Row,I);
      end loop;
      return Work_Vector;
   end Row;

end Kalman_Filter_Data_Types;
```

3.3.1.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in this top level component:

Data types:

The following table summarizes the types required by this part and defined in ancestral units:

Name	Element Type	Index Types	Matrix Type
M_By_N_Statically _Sparse	Kalman_Filter_Elements	Measurement _Indices, State_Indices	Sparse
N_By_N_Diagonal	Kalman_Filter_Elements	State_Indices, State_Indices	Diagonal
N_By_N_Symmetric	Kalman_Filter_Elements	State_Indices, State_Indices	Symmetric
N_By_1 (Vector)	Kalman_Filter_Elements	State_Indices	Vector

3.3.1.2.8 LIMITATIONS

None.

3.3.1.2.9 LLCSC DESIGN

None.

3.3.1.2.10 UNIT DESIGN

None.

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```
package body Kalman_Filter_Data_Types is

-- ------------------------
-- --NAME: Active_H_Vector
-- ------------------------

   function Active_H_Vector (Source : M_By_N_Statically_Sparse.Matrices;
                             Row    : Measurement_Indices)
                            return N_By_1.Vectors is
      Work_Vector : N_By_1.Vectors;
   begin
      for I in State_Indices loop
         Work_Vector (I) := Source (Row, I);
      end loop;
      return Work_Vector;
   end Active_H_Vector;

-- ----------------
-- --NAME: Element
-- ----------------

   function Element (Source : N_By_N_Symmetric.Matrices;
                     Row    : State_Indices;
                     Column : State_Indices)
                    return Kalman_Filter_Elements is
   begin
      return Source (Row, Column);
   end Element;

-- ------------
-- --NAME: Row
-- ------------

   function Row (Source : N_By_N_Symmetric.Matrices;
                 Row    : State_Indices)
                return N_By_1.Vectors is
      Work_Vector : N_By_1.Vectors;
   begin
      for I in State_Indices loop
         Work_Vector (I) := Source (Row,I);
      end loop;
      return Work_Vector;
   end Row;

end Kalman_Filter_Data_Types;
```

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3.3.1.3 AUTOPILOT DATA TYPES (BODY) TLCSC P623 (CATALOG #P93-0)

This part, which is designed as an Ada package, defines simple data types and special operators for use in the Autopilot Package.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.1.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R163.

3.3.1.3.2 LOCAL ENTITIES DESIGN

None.

3.3.1.3.3 INPUT/OUTPUT

None.

3.3.1.3.4 LOCAL DATA

None.

3.3.1.3.5 PROCESS CONTROL

Not applicable.

3.3.1.3.6 PROCESSING

The following describes the processing performed by this part:

```
package body Autopilot_Data_Types is


-------------------------------------------------
-- --Define Operators for Autopilot Data Types-
-------------------------------------------------

-----------------------------------------------------------
-- --Acceleration Feedback * Gain ==> Fin_Deflections-
-----------------------------------------------------------

   function "*" (Left  : Acceleration_Feedbacks_FPS2;
                 Right : FPS2_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Feedbacks_FPS2 (Right));
   end "*";
```

```
   function "*" (Left  : Acceleration_Feedbacks_MPS2;
                 Right : MPS2_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Feedbacks_MPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_Gees;
                 Right : Gees_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
             (Left * Acceleration_Feedbacks_Gees (Right));
   end "*";


   function "*" (Left  : Acceleration_Feedbacks_FPS2;
                 Right : FPS2_to_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Feedbacks_FPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_MPS2;
                 Right : MPS2_to_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Feedbacks_MPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_Gees;
                 Right : Gees_to_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Feedbacks_Gees (Right));
   end "*";

-------------------------------------------------------
-- --Acceleration Commands * Gain ==> Fin Deflections-
-------------------------------------------------------

   function "*" (Left  : Acceleration_Commands_FPS2;
                 Right : FPS2_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Commands_FPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_MPS2;
                 Right : MPS2_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
```

```
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Commands_MPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Gees;
                 Right : Gees_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Commands_Gees (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_FPS2;
                 Right : FPS2_to_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Commands_FPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_MPS2;
                 Right : MPS2_to_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Commands_MPS2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Gees;
                 Right : Gees_to_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Commands_Gees (Right));
   end "*";

-----------------------------------------------
-- --Feedback Rates * Gain ==> Fin Deflections-
-----------------------------------------------

-- --Ambiguity in the meaning of the "*" operator has required changing the
-- --standard order for explicit type conversion.  The bodies of the next two
-- --functions perform explicit type conversion on the "Left" operand to avoid
-- --ambiguity with subprograms derived from the type declarations of Feedback
-- --_Rates_Degrees and Feedback_Rates_Radians.

   function "*" (Left  : Feedback_Rates_Degrees;
                 Right : DPS_to_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (DPS_to_Degrees_Gain (Left) * Right);
   end "*";

   function "*" (Left  : Feedback_Rates_Radians;
                 Right : RPS_to_Radians_Gain)
```

```
                return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (RPS_to_Radians_Gain (Left) * Right);
   end "*";

-------------------------------------
-- --Roll Commands * Gain ==> Angle-
-------------------------------------

   function "*" (Left  : Roll_Commands_Degrees;
                 Right : Gain_in_Degrees)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Roll_Commands_Degrees (Right));
   end "*";

   function "*" (Left  : Roll_Commands_Radians;
                 Right : Gain_in_Radians)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Roll_Commands_Radians (Right));
   end "*";

-------------------------------------------------------------------------------
-- --Acceleration Commands + Acceleration Feedbacks ==> Acceleration Commands-
-------------------------------------------------------------------------------

   function "+" (Left  : Acceleration_Commands_FPS2;
                 Right : Acceleration_Feedbacks_FPS2)
                 return Acceleration_Commands_FPS2 is
   begin
      return Left + Acceleration_Commands_FPS2 (Right);
   end "+";

   function "+" (Left  : Acceleration_Commands_MPS2;
                 Right : Acceleration_Feedbacks_MPS2)
                 return Acceleration_Commands_MPS2 is
   begin
      return Left + Acceleration_Commands_MPS2 (Right);
   end "+";

   function "+" (Left  : Acceleration_Commands_Gees;
                 Right : Acceleration_Feedbacks_Gees)
                 return Acceleration_Commands_Gees is
   begin
      return Left + Acceleration_Commands_Gees (Right);
   end "+";

-------------------------------------------------------------------------------
-- --Acceleration Commands - Acceleration Feedbacks ==> Acceleration Commands-
-------------------------------------------------------------------------------

   function "-" (Left  : Acceleration_Commands_FPS2;
                 Right : Acceleration_Feedbacks_FPS2)
```

```
                    return Acceleration_Commands_FPS2 is
   begin
      return Left - Acceleration_Commands_FPS2 (Right);
   end "-";

   function "-" (Left  : Acceleration_Commands_MPS2;
                 Right : Acceleration_Feedbacks_MPS2)
                 return Acceleration_Commands_MPS2 is
   begin
      return Left - Acceleration_Commands_MPS2 (Right);
   end "-";

   function "-" (Left  : Acceleration_Commands_Gees;
                 Right : Acceleration_Feedbacks_Gees)
                 return Acceleration_Commands_Gees is
   begin
      return Left - Acceleration_Commands_Gees (Right);
   end "-";

-------------------------------------------------------------
-- --Roll Commands - Missile Attitudes ==> Roll Commands-
-------------------------------------------------------------

   function "-" (Left  : Roll_Commands_Degrees;
                 Right : Missile_Attitudes_Degrees)
                 return Roll_Commands_Degrees is
   begin
      return Left - Roll_Commands_Degrees (Right);
   end "-";

   function "-" (Left  : Roll_Commands_Radians;
                 Right : Missile_Attitudes_Radians)
                 return Roll_Commands_Radians is
   begin
      return Left - Roll_Commands_Radians (Right);
   end "-";

end Autopilot_Data_Types;
```

3.3.1.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.1.3.8 LIMITATIONS

None.

3.3.1.3.9 LLCSC DESIGN

None.

3.3.1.3.10 UNIT DESIGN

None.

```
package body Autopilot_Data_Types is


-------------------------------------------------
-- --Define Operators for Autopilot Data Types-
-------------------------------------------------

-----------------------------------------------------------
-- --Acceleration Feedback * Gain ==> Fin_Deflections-
-----------------------------------------------------------

   function "*" (Left  : Acceleration_Feedbacks_Fps2;
                 Right : Fps2_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Feedbacks_Fps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_Mps2;
                 Right : Mps2_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Feedbacks_Mps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_Gees;
                 Right : Gees_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
             (Left * Acceleration_Feedbacks_Gees (Right));
   end "*";


   function "*" (Left  : Acceleration_Feedbacks_Fps2;
                 Right : Fps2_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Feedbacks_Fps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_Mps2;
                 Right : Mps2_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Feedbacks_Mps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Feedbacks_Gees;
                 Right : Gees_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
```

```
      return Fin_Deflections_Radians
                (Left * Acceleration_Feedbacks_Gees (Right));
   end "*";

-------------------------------------------------------
-- --Acceleration Commands * Gain ==> Fin Deflections-
-------------------------------------------------------

   function "*" (Left  : Acceleration_Commands_Fps2;
                 Right : Fps2_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Commands_Fps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Mps2;
                 Right : Mps2_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Commands_Mps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Gees;
                 Right : Gees_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Acceleration_Commands_Gees (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Fps2;
                 Right : Fps2_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Commands_Fps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Mps2;
                 Right : Mps2_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Commands_Mps2 (Right));
   end "*";

   function "*" (Left  : Acceleration_Commands_Gees;
                 Right : Gees_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Acceleration_Commands_Gees (Right));
   end "*";

-----------------------------------------------
```

```
-- --Feedback Rates * Gain ==> Fin Deflections-
-----------------------------------------------

-- --Ambiguity in the meaning of the "*" operator has required changing the
-- --standard order for explicit type conversion. The bodies of the next two
-- --functions perform explicit type conversion on the "Left" operand to avoid
-- --ambiguity with subprograms derived from the type declarations of Feedback
-- --_Rates_Degrees and Feedback_Rates_Radians.

   function "*" (Left  : Feedback_Rates_Degrees;
                 Right : Dps_To_Degrees_Gain)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Dps_To_Degrees_Gain (Left) * Right);
   end "*";

   function "*" (Left  : Feedback_Rates_Radians;
                 Right : Rps_To_Radians_Gain)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Rps_To_Radians_Gain (Left) * Right);
   end "*";

-------------------------------------
-- --Roll Commands * Gain ==> Angle-
-------------------------------------

   function "*" (Left  : Roll_Commands_Degrees;
                 Right : Gain_In_Degrees)
                 return Fin_Deflections_Degrees is
   begin
      return Fin_Deflections_Degrees
                (Left * Roll_Commands_Degrees (Right));
   end "*";

   function "*" (Left  : Roll_Commands_Radians;
                 Right : Gain_In_Radians)
                 return Fin_Deflections_Radians is
   begin
      return Fin_Deflections_Radians
                (Left * Roll_Commands_Radians (Right));
   end "*";

-------------------------------------------------------------------------------
-- --Acceleration Commands + Acceleration Feedbacks ==> Acceleration Commands-
-------------------------------------------------------------------------------

   function "+" (Left  : Acceleration_Commands_Fps2;
                 Right : Acceleration_Feedbacks_Fps2)
                 return Acceleration_Commands_Fps2 is
   begin
      return Left + Acceleration_Commands_Fps2 (Right);
   end "+";

   function "+" (Left  : Acceleration_Commands_Mps2;
```

```
                Right : Acceleration_Feedbacks_Mps2)
                return Acceleration_Commands_Mps2 is
   begin
      return Left + Acceleration_Commands_Mps2 (Right);
   end "+";

   function "+" (Left  : Acceleration_Commands_Gees;
                Right : Acceleration_Feedbacks_Gees)
                return Acceleration_Commands_Gees is
   begin
      return Left + Acceleration_Commands_Gees (Right);
   end "+";

-------------------------------------------------------------------------------
-- --Acceleration Commands - Acceleration Feedbacks ==> Acceleration Commands-
-------------------------------------------------------------------------------

   function "-" (Left  : Acceleration_Commands_Fps2;
                Right : Acceleration_Feedbacks_Fps2)
                return Acceleration_Commands_Fps2 is
   begin
      return Left - Acceleration_Commands_Fps2 (Right);
   end "-";

   function "-" (Left  : Acceleration_Commands_Mps2;
                Right : Acceleration_Feedbacks_Mps2)
                return Acceleration_Commands_Mps2 is
   begin
      return Left - Acceleration_Commands_Mps2 (Right);
   end "-";

   function "-" (Left  : Acceleration_Commands_Gees;
                Right : Acceleration_Feedbacks_Gees)
                return Acceleration_Commands_Gees is
   begin
      return Left - Acceleration_Commands_Gees (Right);
   end "-";

-------------------------------------------------------------
-- --Roll Commands - Missile Attitudes ==> Roll Commands-
-------------------------------------------------------------

   function "-" (Left  : Roll_Commands_Degrees;
                Right : Missile_Attitudes_Degrees)
                return Roll_Commands_Degrees is
   begin
      return Left - Roll_Commands_Degrees (Right);
   end "-";

   function "-" (Left  : Roll_Commands_Radians;
                Right : Missile_Attitudes_Radians)
                return Roll_Commands_Radians is
   begin
      return Left - Roll_Commands_Radians (Right);
   end "-";

end Autopilot_Data_Types;
```

3.3.2 NAVIGATION

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3.3.2.1 COMMON_NAVIGATION_PARTS (PACKAGE BODY) TLCSC P001 (CATALOG #P208-0)

This part, which is designed as an Ada package, contains specifications for all CAMP parts which can be used in either a Wander Azimuth or a North Pointing navigation coordinate system environment.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.1.1 REQUIREMENTS ALLOCATION

The following chart summarizes the allocation of CAMP requirements to this part:

Name	Requirement Number
Altitude_Integration	R002
Compute_Ground_Velocity	R003
Compute_Gravitational_Acceleration_Lat_In	R005
Compute_Gravitational_Acceleration_Sin_Lat_In	R006
Compute_Heading	R009
Update_Velocity	R010
Compute_Scalar_Velocity	R039
Compute_Rotation_Increments	R157

3.3.2.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.3 INPUT/OUTPUT

None.

3.3.2.1.4 LOCAL DATA

None.

3.3.2.1.5 PROCESS CONTROL

Not applicable.

3.3.2.1.6 PROCESSING

The following describes the processing performed by this part:

```
package body Common_Navigation_Parts is

   package body Altitude_Integration is separate;
```

```
   function Compute_Ground_Velocity
               (East_Velocity  : Velocities;
                North_Velocity : Velocities) return Velocities is separate;

   function Compute_Gravitational_Acceleration_Lat_In
               (Current_Altitude : Distances;
                Current_Latitude : Earth_Positions)
               return Accelerations is separate;

   function Compute_Gravitational_Acceleration_Sin_Lat_In
               (Current_Altitude     : Distances;
                Sin_Current_Latitude : Sin_Cos_Ratio)
               return Accelerations is separate;

   function Compute_Heading (East_Velocity  : Velocities;
                             North_Velocity : Velocities)
                            return Headings is separate;

   package body Update_Velocity is separate;

   function Scalar_Velocity (Velocity_In : Velocity_Vectors)
                            return Velocities is separate;

   function Compute_Rotation_Increments
               (Platform_Rotation_Rate : Angular_Velocity_Vectors;
                Delta_Time             : Intervals)
               return Angle_Vectors is separate;

end Common_Navigation_Parts;
```

3.3.2.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.8 LIMITATIONS

None.

3.3.2.1.9 LLCSC DESIGN

3.3.2.1.9.1 ALTITUDE_INTEGRATION PACKAGE DESIGN (CATALOG #P209-0)

This package updates the altitude using trapezoidal integration of the earth-relative vertical velocity. It has the ability to reinitialize the previous values of the vertical velocity and the altitude, and the ability to calculate a new value for altitude.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.1.9.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R002.

3.3.2.1.9.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Distances	floating point type	Data type used to define distance measurements
Intervals	floating point type	Data type used to define time measurements
Velocities	floating point type	Data type used to define velocity measurements

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Default_Delta_Time	Intervals	N/A	Default time over which integration is to be performed
Initial_Vertical_Velocity	Velocities	N/A	Initial vertical velocity to be used by the Integrate function
Initial_Altitude	Distances	N/A	Initial altitude to be used by Integrate function

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator used to define the operation: Velocities * Intervals => Distances

3.3.2.1.9.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Previous_Vertical_Velocity	Velocities	N/A	Previous value of the vertical velocity
Previous_Altitude	Distances	N/A	Previously calculated altitude

3.3.2.1.9.1.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
package body Altitude_Integration is

-- ---------------------
-- --local declarations-
-- ---------------------

   Previous_Vertical_Velocity : Velocities := Initial_Vertical_Velocity;
   Previous_Altitude          : Distances  := Initial_Altitude;

end Altitude_Integration;
```

3.3.2.1.9.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.9.1.8 LIMITATIONS

None.

3.3.2.1.9.1.9 LLCSC DESIGN

None.

3.3.2.1.9.1.10 UNIT DESIGN

3.3.2.1.9.1.10.1 REINITIALIZE UNIT DESIGN

This procedure reinitializes the previous values for vertical velocity and altitude. These values are required by the Integrate function.

3.3.2.1.9.1.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R002.

3.3.2.1.9.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.1.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Value	Description
New_Vertical_Velocity	Velocity	In	Value to be used to reinitialize previous vertical velocity
New_Altitude	Distance	In	Value to be used to reinitialize previous altitude

3.3.2.1.9.1.10.1.4 LOCAL DATA

None.

3.3.2.1.9.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Reinitialize (New_Vertical_Velocity : in Velocities;
                        New_Altitude          : in Distances) is

begin
```

```
    Previous_Altitude          := New_Altitude;
    Previous_Vertical_Velocity := New_Vertical_Velocity;

  end Reinitialize;
```

3.3.2.1.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic parameters to the enclosing package body:

Name	Type	Description
Distances	floating point type	Data type used to define distance measurements
Intervals	floating point type	Data type used to define time measurements
Velocities	floating point type	Data type used to define velocity measurements

Data objects:

The following table describes the data objects required by this part and located in the package body of Altitude_Integration:

Name	Type	Value	Description
Previous_Vertical_Velocity	Velocities	N/A	Previous value of the vertical velocity
Previous_Altitude	Distances	N/A	Previously calculated altitude

3.3.2.1.9.1.10.1.8 LIMITATIONS

None.

3.3.2.1.9.1.10.2 INTEGRATE UNIT DESIGN

This procedure calculates the new altitude using trapezoidal integration of the earth-relative vertical velocity. It also updates previous velocity and altitude variables.

3.3.2.1.9.1.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R002.

3.3.2.1.9.1.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.1.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Value	Description
Vertical_Velocity	Velocity	N/A	Current earth-relative vertical velocity of the missile
Delta_Time	Interval	N/A	Time interval over which the integration is to take place

3.3.2.1.9.1.10.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained local to this part:

Name	Type	Value	Description
Altitude	Distances	N/A	Altitude being calculated

3.3.2.1.9.1.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.1.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
   function Integrate (Vertical_Velocity : Velocities;
                       Delta_Time        : Intervals := Default_Delta_Time)
                      return Distances is

--    --------------------
--    --local declarations
--    --------------------

      Altitude : Distances;
```

```
-- -------------------------
-- --begin function Integrate
-- -------------------------

   begin

      Altitude := Previous_Altitude +
                  ( (Vertical_Velocity + Previous_Vertical_Velocity) *
                    (0.5 * Delta_Time) );

      Previous_Vertical_Velocity := Vertical_Velocity;
      Previous_Altitude          := Altitude;

      return Altitude;

   end Integrate;
```

3.3.2.1.9.1.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic parameters to the enclosing package body:

Name	Type	Description
Distances	floating point type	Data type used to define distance measurements
Intervals	floating point type	Data type used to define time measurements
Velocities	floating point type	Data type used to define velocity measurements

Data objects:

The following table describes the data objects required by this part and located in the package body of Altitude_Integration:

Name	Type	Value	Description
Previous_Vertical_Velocity	Velocities	N/A	Previous value of the vertical velocity
Previous_Altitude	Distances	N/A	Previously calculated altitude

3.3.2.1.9.1.10.2.8 LIMITATIONS

None.

3.3.2.1.9.2 UPDATE_VELOCITY PACKAGE DESIGN (CATALOG #P214-0)

This package contains the subroutines required to compute the current velocity (in vector form).

It consists of reinitialize, a procedure which reinitializes the value of the Velocity vector, and Update, a function which computes the current velocity vector given the velocity change vector, the time interval over which the velocity changes were accumulated, Coriolis acceleration vector, and acceleration due to gravity.

The computations performed by the update function are as follows:

```
New Velocity := Previous Velocity + Delta Velocity -
                ( (Coriolis Acceleration -
                   Gravitational Acceleration) * Delta Time)
```

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.1.9.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R010.

3.3.2.1.9.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

This part's generic parameters were previously defined in the package specification of Common_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Velocity_Vectors	private	Contains the east, north, and vertical components of the missile's current velocity
Intervals	floating point type	Data type used to define time measurements
Accelerations	floating point type	Data type used to define acceleration measurements
Indices	scalar type	Used to dimension Acceleration_Vectors
Acceleration_Vectors	array	Array of Accelerations

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Default_ Gravity	Acceleration_ Vectors	N/A	Vector defining acceleration due to gravity (positive in the up direction)
Initial_ Velocity	Velocity_ Vectors	N/A	Initial velocity values used by Update function

Subprograms:

The following table describes the generic formal subroutines (operators) required by this part:

Name	Type	Description
"*"	function	Vector-scalar multiplication operator defining the operation: Acceleration_Vectors * Intervals => Velocity_Vectors
Sparse_Right_ XY_Subtract	function	Subtraction operator operating on acceleration vectors where the assumption is made that the third element of the right input vector equals 0
"+"	function	Vector-vector addition operator defining the operation: Velocity_Vectors + Velocity_Vectors => Velocity_Vectors
"-"	function	Vector-vector subtraction operator defining the operation: Velocity_Vectors - Velocity_Vectors => Velocity_Vectors

3.3.2.1.9.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Previous_Velocity	Velocity_Vector	N/A	Velocity vector calculated during previous update operation

3.3.2.1.9.2.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
package body Update_Velocity is

-- ------------------
-- --local variables-
-- ------------------

   Previous_Velocity : Velocity_Vectors := Initial_Velocity;

end Update_Velocity;
```

3.3.2.1.9.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.9.2.8 LIMITATIONS

None.

3.3.2.1.9.2.9 LLCSC DESIGN

None.

3.3.2.1.9.2.10 UNIT DESIGN

3.3.2.1.9.2.10.1 REINITIALIZE UNIT DESIGN

This procedure reinitializes the previous velocity vector required by the update function.

3.3.2.1.9.2.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R010.

3.3.2.1.9.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.2.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Value	Description
New_Velocity	Velocity_Vectors	In	New value for the previous_ velocity_vector

3.3.2.1.9.2.10.1.4 LOCAL DATA

None.

3.3.2.1.9.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Reinitialize (New_Velocity : in Velocity_Vectors) is
begin
   Previous_Velocity := New_Velocity;
end Reinitialize;
```

3.3.2.1.9.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic parameters to the enclosing package body:

Name	Type	Description
Velocity_Vectors	private	Contains the east, north, and vertical components of the missile's current velocity

Data objects:

The following table summarizes the objects required by this part and defined in the enclosing package body:

Name	Type	Value	Description
Previous_Velocity	Velocity_Vectors	N/A	Velocity vector calculated during previous update operation

3.3.2.1.9.2.10.1.8 LIMITATIONS

None.

3.3.2.1.9.2.10.2 UPDATE UNIT DESIGN

This function computes the current velocity vector given the velocity change vector, the time interval over which the velocity changes were accumulated, the coriolis acceleration vector, and the acceleration due to gravity.

The computations performed are as follows:

```
New Velocity := Previous Velocity + Delta Velocity -
                ( (Coriolis Acceleration -
                   Gravitational Acceleration) * Delta Time)
```

3.3.2.1.9.2.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R010.

3.3.2.1.9.2.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.2.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Value	Description
Nominal_Delta_Velocity	Velocity_Vectors	N/A	Contains the east, north, and vertical components of the change in the missile's velocity
Coriolis_Acceleration	Acceleration_Vectors	N/A	Contains the east, north, and vertical components of the coriolis acceleration
Delta_Time	Intervals	N/A	Time interval over which the velocity changes occurred

3.3.2.1.9.2.10.2.4 LOCAL DATA

None.

3.3.2.1.9.2.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.2.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
   function Update (Nominal_Delta_Velocity : Velocity_Vectors;
                    Coriolis_Acceleration  : Acceleration_Vectors;
                    Delta_Time             : Intervals;
                    Gravity                : Acceleration_Vectors
                                               := Default_Gravity)
                   return Velocity_Vectors is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      Current_Velocity  : Velocity_Vectors;
      Temp_A_V          : Acceleration_Vectors;
      Temp_V_V          : Velocity_Vectors;

-- ------------------------------
-- --beginning of function Update
```

```
-- ------------------------------

   begin

      Temp_A_V := Sparse_Right_XY_Subtract(Coriolis_Acceleration, Gravity);
      Temp_V_V := Temp_A_V * Delta_Time;

      Current_Velocity  := Previous_Velocity +
                           Nominal_Delta_Velocity -
                           Temp_V_V;
      Previous_Velocity := Current_Velocity;

      return Current_Velocity;

   end Update;
```

3.3.2.1.9.2.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic parameters to the enclosing package body:

Name	Type	Description
Velocity_Vectors	private	Contains the east, north, and vertical components of the missile's current velocity
Intervals	floating point type	Data type used to define time measurements
Accelerations	floating point type	Data type used to define acceleration measurements
Indices	scalar type	Used to dimension Acceleration_Vector
Acceleration_Vectors	array	Array of Acceleration

Data objects:

The following table summarizes the objects required by this part and defined as generic parameters to the enclosing package:

Name	Type	Value	Description
Default_ Gravity	Acceleration_ Vectors	N/A	Vector defining acceleration due to gravity (positive in the up direction)

The following table summarizes the objects required by this part and defined in the enclosing package body:

Name	Type	Value	Description
Previous_Velocity	Velocity_Vectors	N/A	Velocity vector calculated during previous update operation

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined as generic parameters to the enclosing package:

Name	Type	Description
"*"	function	Vector-scalar multiplication operator defining the operation: Acceleration_Vectors * Intervals => Velocity_Vectors
Sparse_Right_XY_Subtract	function	Subtraction operator operating on acceleration vectors where the assumption is made that the third element of the right input vector equals 0
"+"	function	Vector-vector addition operator defining the operation: Velocity_Vectors + Velocity_Vectors => Velocity_Vectors
"-"	function	Vector-vector subtraction operator defining the operation: Velocity_Vectors - Velocity_Vectors => Velocity_Vectors

3.3.2.1.9.2.10.2.8 LIMITATIONS

None.

3.3.2.1.9.2.10.3 CURRENT_VELOCITY UNIT DESIGN

This function returns the previous velocity (i.e. the current velocity).

3.3.2.1.9.2.10.3.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.1.9.2.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.9.2.10.3.3 INPUT/OUTPUT

None.

3.3.2.1.9.2.10.3.4 LOCAL DATA

None.

3.3.2.1.9.2.10.3.5 PROCESS CONTROL

Not applicable.

3.3.2.1.9.2.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
function Current_Velocity return Velocity_Vectors is
begin
   return Previous_Velocity;
end Current_Velocity;
```

3.3.2.1.9.2.10.3.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP-LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in this top-level component:

Data types:

The following table summarizes the types required by this part and defined as generic parameters to the enclosing package body:

Name	Type	Description
Velocity_Vectors	private	Contains the east, north, and vertical components of the missile's current velocity

Data objects:

The following table summarizes the objects required by this part and defined in the enclosing package body:

Name	Type	Value	Description
Previous_Velocity	Velocity_Vectors	N/A	Velocity vector calculated during previous update operation

3.3.2.1.9.2.10.3.8 LIMITATIONS

None.

3.3.2.1.10 UNIT DESIGN

3.3.2.1.10.1 COMPUTE_GROUND_VELOCITY UNIT DESIGN (CATALOG #P210-0)

This function calculates the ground (i.e. horizontal) velocity of the missile from the east and north components of the missile velocity.

The ground velocity is as computed as follows:

```
GVel := Sqrt(EVel**2 + NVel **2)

where EVel = East Velocity
      NVel = North Velocity
```

3.3.2.1.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R003.

3.3.2.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification of Common_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Velocities	floating point type	Data type used to define velocity measurements
Velocity_Squared	floating point type	Data type resulting from multiply two objects of type velocity

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Velocities * Velocities => Velocity_Squared
Sqrt	function	Square root function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
East_Velocity	Velocities	In	Current east velocity of missile
North_Velocity	Velocities	In	Current north velocity of missile

3.3.2.1.10.1.4 LOCAL DATA

None.

3.3.2.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
function Compute_Ground_Velocity
            (East_Velocity  : Velocities;
             North_Velocity : Velocities) return Velocities is

begin

   return Sqrt(East_Velocity  * East_Velocity +
               North_Velocity * North_Velocity);
```

```
end Compute_Ground_Velocity;
```

3.3.2.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.10.1.8 LIMITATIONS

None.

3.3.2.1.10.2 COMPUTE_GRAVITATIONAL_ACCELERATION_LAT_IN UNIT DESIGN (CATALOG #P211-0)

The part computes the vertical acceleration due to gravity given the missile's current altitude and latitude. The calculations performed are as follows:

```
Grav := NGrav * (1 - (2*Alt/EER) + (GCF * Sin(Lat)**2) )

where NGrav = Nominal Gravity
      GCF   = Gravity Coefficient
      EER   = Earth Equatorial Radius
```

3.3.2.1.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R005.

3.3.2.1.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

This part's generic parameters were previously defined in the package specification for Common_Navigation_Parts.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Accelerations	floating point type	Data type used to define acceleration measurements
Distances	floating point type	Data type used to define distance measurements
Earth_Positions	floating point type	Data type used to define latitude and longitude measurements
Inverse_ Distances	floating point type	Data type used to define 1/distance measurements
Real	floating point type	Data type of Gravity_Coefficient
Sin_Cos_Ratio	floating point type	Data type used to define the results of a Sin calculation

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Nominal_Gravity	Accelerations	N/A	Value of absolute mean normal gravity
One_Over_Earth_ Radius	Distances	N/A	Value for 1/earth equatorial radius
Gravity_Coefficient	Real	N/A	Coefficient of.gravity

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Accelerations * Real => Accelerations
"*"	function	Multiplication operator defining the operation: Sin_Cos_Ratio * Real => Real
"*"	function	Division operator defining the operation: Distances * Inverse_Distances => Real
Sin	function	Sine function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Current_Altitude	Distances	In	Current altitude of the missile
Current_Latitude	Earth_Positions	In	Current latitude of the missile

3.3.2.1.10.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Sin_of_Lat	Sin_Cos_Ratio	N/A	Sine of Current_Latitude

3.3.2.1.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.1.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
function Compute_Gravitational_Acceleration_Lat_In
            (Current_Altitude : Distances;
             Current_Latitude : Earth_Positions) return Accelerations is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Sin_of_Lat : Sin_Cos_Ratio;

------------------------------------------------------------
--begin function Compute_Gravitational_Acceleration_Lat_In
------------------------------------------------------------

begin

   Sin_of_Lat := Sin(Current_Latitude);
   return Nominal_Gravity *
         (1.0 -
          (Current_Altitude+Current_Altitude) * One_Over_Earth_Radius  +
          Sin_of_Lat * Sin_of_Lat * Gravity_Coefficient
          );

end Compute_Gravitational_Acceleration_Lat_In;
```

3.3.2.1.10.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.10.2.8 LIMITATIONS

None.

3.3.2.1.10.3 COMPUTE_GRAVITATIONAL_ACCELERATION_SIN_LAT_IN UNIT DESIGN (CATALOG #P212-0)

Given the missile's current altitude and the sine of the current latitude, this function computes the vertical acceleration due to gravity. The computations are performed as follows:

```
Grav := NGrav * (1 - (2 * Alt/EER) + (GCF * SinLat**2)))
```

where NGrav = Nominal Gravity
GCF = Gravity Coefficient
EER = Earth Equatorial Radius

3.3.2.1.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R006.

3.3.2.1.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.10.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

This part's generic parameters were previously defined in the package specification of Common_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Accelerations	floating point type	Data type used to define acceleration measurements
Distances	floating point type	Data type used to define distance measurements
Inverse_Distances	floating point type	Data type used to define 1/distance measurements
Real	floating point type	Data type of Gravity_Coefficient
Sin_Cos_Ratio	floating point type	Data type used to define the results of a Sin calculation

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Nominal_Gravity	Accelerations	N/A	Value of absolute mean normal gravity
One_Over_Earth_Radius	Distances	N/A	Value for 1/earth equatorial radius
Gravity_Coefficient	Real	N/A	Coefficient of gravity

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Accelerations * Real => Accelerations
"*"	function	Multiplication operator defining the operation: Sin_Cos_Ratio * Real => Real
"*"	function	Division operator defining the operation: Distances * Inverse_Distances => Real

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Current_Altitude	Distances	In	Current altitude of the missile
Sin_Current_Latitude	Sin_Cos_Ratio	In	Sine of the current latitude of the missile

3.3.2.1.10.3.4 LOCAL DATA

None.

3.3.2.1.10.3.5 PROCESS CONTROL

Not applicable.

3.3.2.1.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
function Compute_Gravitational_Acceleration_Sin_Lat_In
            (Current_Altitude     : Distances;
             Sin_Current_Latitude : Sin_Cos_Ratio)
            return Accelerations is

begin

   return Nominal_Gravity *
          (1.0 -
           (Current_Altitude+Current_Altitude) * One_Over_Earth_Radius +
           Sin_Current_Latitude * Sin_Current_Latitude *
             Gravity_Coefficient
           );

end Compute_Gravitational_Acceleration_Sin_Lat_In;
```

3.3.2.1.10.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.10.3.8 LIMITATIONS

None.

3.3.2.1.10.4 COMPUTE_HEADING UNIT DESIGN (CATALOG #P213-0)

This function computes the missile's current heading given the missile's current east and north velocities.

The computations are performed as follows:

Hdg := Arctan(EVel / NVel)

where EVel = East velocity
NVel = North velocity

3.3.2.1.10.4.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R009.

3.3.2.1.10.4.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.10.4.3 INPUT/OUTPUT

GENERIC PARAMETERS:

This part's generic parameters were previously defined in the package specification of Common_Navigation_Parts.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Velocities	floating point type	Data type defining velocity measurements
Headings	floating point type	Data type defining angular measurement

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Arctan	function	Arctangent function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
East_Velocity	Velocities	In	Current east velocity of missile
North_Velocity	Velocities	In	Current north velocity of missile

3.3.2.1.10.4.4 LOCAL DATA

None.

3.3.2.1.10.4.5 PROCESS CONTROL

Not applicable.

3.3.2.1.10.4.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
function Compute_Heading (East_Velocity  : Velocities;
                          North_Velocity : Velocities) return Headings is

begin

-- --operation performed will be y/x (want East/North)
   return Arctan2 (Y => East_Velocity,
                   X => North_Velocity);

end Compute_Heading;
```

3.3.2.1.10.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.10.4.8 LIMITATIONS

None.

3.3.2.1.10.5 SCALAR_VELOCITY UNIT DESIGN (CATALOG #P215-0)

This function computes the scalar velocity given a velocity vector.

3.3.2.1.10.5.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R039.

3.3.2.1.10.5.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.10.5.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined when this part was specified.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Velocities	floating point type	Data type defining velocity measurements
Velocity_Vectors	private	Data type containing a velocity vector values

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Vector_Length	function	Function used to calculate the length of a vector

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Velocity_In	Velocity_Vectors	In	Missile's current velocity vector

3.3.2.1.10.5.4 LOCAL DATA

None.

3.3.2.1.10.5.5 PROCESS CONTROL

Not applicable.

3.3.2.1.10.5.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
function Scalar_Velocity (Velocity_In : Velocity_Vectors)
                                  return Velocities is
begin
```

```
   return Vector_Length(Velocity_In);

end Scalar_Velocity;
```

3.3.2.1.10.5.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.10.5.8 LIMITATIONS

None.

3.3.2.1.10.6 COMPUTE_ROTATION_INCREMENTS (FUNCTION BODY) UNIT DESIGN (CATALOG #P216-0)

This function computes the rotation rate increments of the navigation coordinate system with respect to inertial space.

3.3.2.1.10.6.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R157.

3.3.2.1.10.6.2 LOCAL ENTITIES DESIGN

None.

3.3.2.1.10.6.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined when this part was specified.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angle_Vectors	private type	Vector containing the east, north, vertical components of the rotation rate increments
Angular_Velocity_Vectors	private type	Vector containing the east, north, and vertical components of the total platform rate
Intervals	floating point type	Data type defining time measurements

Subprograms:

The following table describes the generic formal subroutines (operators) required by this part:

Name	Left Input Type	Right Input Type	Result Type
"*"	Angular_Velocity_Vectors	Intervals	Angle_Vectors

FORMAL PARAMETERS:

The following table describes the formal parameters of this part:

Name	Type	Mode	Description
Platform_ Rotation_Rate	Angular_ Velocity_Vectors	In	Contains the nominal components of the total rotation rate
Delta_Time	Intervals	In	Time interval over which the increments are to be calculated

3.3.2.1.10.6.4 LOCAL DATA

None.

3.3.2.1.10.6.5 PROCESS CONTROL

Not applicable.

3.3.2.1.10.6.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Common_Navigation_Parts)
function Compute_Rotation_Increments
            (Platform_Rotation_Rate : Angular_Velocity_Vectors;
             Delta_Time             : Intervals)
            return Angle_Vectors is
begin

   return Platform_Rotation_Rate * Delta_Time;

end Compute_Rotation_Increments;
```

3.3.2.1.10.6.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.1.10.6.8 LIMITATIONS

None.

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```
package body Common_Navigation_Parts is

   package body Altitude_Integration is separate;

   function Compute_Ground_Velocity
               (East_Velocity  : Velocities;
                North_Velocity : Velocities) return Velocities is separate;

   function Compute_Gravitational_Acceleration_Lat_In
               (Current_Altitude : Distances;
                Current_Latitude : Earth_Positions)
               return Accelerations is separate;

   function Compute_Gravitational_Acceleration_Sin_Lat_In
               (Current_Altitude     : Distances;
                Sin_Current_Latitude : Sin_Cos_Ratio)
               return Accelerations is separate;

   function Compute_Heading (East_Velocity  : Velocities;
                             North_Velocity : Velocities)
                            return Headings is separate;

   package body Update_Velocity is separate;

   function Scalar_Velocity (Velocity_In : Velocity_Vectors)
                            return Velocities is separate;

   function Compute_Rotation_Increments
               (Platform_Rotation_Rate : Angular_Velocity_Vectors;
                Delta_Time             : Intervals)
               return Angle_Vectors is separate;

end Common_Navigation_Parts;
```

```
separate (Common_Navigation_Parts)
package body Altitude_Integration is

-- ---------------------
-- --local declarations-
-- ---------------------

   Previous_Vertical_Velocity : Velocities := Initial_Vertical_Velocity;
   Previous_Altitude          : Distances  := Initial_Altitude;

pragma PAGE;
   procedure Reinitialize (New_Vertical_Velocity : in Velocities;
                           New_Altitude          : in Distances) is

   begin

      Previous_Altitude          := New_Altitude;
      Previous_Vertical_Velocity := New_Vertical_Velocity;

    end Reinitialize;

pragma PAGE;
   function Integrate (Vertical_Velocity : Velocities;
                       Delta_Time        : Intervals := Default_Delta_Time)
                      return Distances is

--    --------------------
--    --local declarations
--    --------------------

      Altitude : Distances;

-- --------------------------
-- --begin function Integrate
-- --------------------------

   begin

      Altitude := Previous_Altitude +
                  ( (Vertical_Velocity + Previous_Vertical_Velocity) *
                    (0.5 * Delta_Time) );

      Previous_Vertical_Velocity := Vertical_Velocity;
      Previous_Altitude          := Altitude;

      return Altitude;

   end Integrate;

end Altitude_Integration;
```

```
separate (Common_Navigation_Parts)
function Compute_Ground_Velocity
            (East_Velocity  : Velocities;
             North_Velocity : Velocities) return Velocities is

begin

   return Sqrt(East_Velocity  * East_Velocity +
               North_Velocity * North_Velocity);

end Compute_Ground_Velocity;
```

```
separate (Common_Navigation_Parts)
function Compute_Gravitational_Acceleration_Lat_In
            (Current_Altitude : Distances;
             Current_Latitude : Earth_Positions) return Accelerations is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Sin_Of_Lat : Sin_Cos_Ratio;

--------------------------------------------------------------
--begin function Compute_Gravitational_Acceleration_Lat_In
--------------------------------------------------------------

begin

   Sin_Of_Lat := Sin(Current_Latitude);
   return Nominal_Gravity *
          (1.0 -
           (Current_Altitude+Current_Altitude) * One_Over_Earth_Radius  +
           Sin_Of_Lat * Sin_Of_Lat * Gravity_Coefficient
           );

end Compute_Gravitational_Acceleration_Lat_In;
```

```
separate (Common_Navigation_Parts)
function Compute_Gravitational_Acceleration_Sin_Lat_In
           (Current_Altitude     : Distances;
            Sin_Current_Latitude : Sin_Cos_Ratio)
           return Accelerations is

begin

   return Nominal_Gravity *
          (1.0 -
           (Current_Altitude+Current_Altitude) * One_Over_Earth_Radius +
           Sin_Current_Latitude * Sin_Current_Latitude *
             Gravity_Coefficient
           );

end Compute_Gravitational_Acceleration_Sin_Lat_In;
```

```
separate (Common_Navigation_Parts)
function Compute_Heading (East_Velocity  : Velocities;
                          North_Velocity : Velocities) return Headings is

begin

-- --operation performed will be y/x (want East/North)
   return Arctan2 (Y => East_Velocity,
                   X => North_Velocity);

end Compute_Heading;
```

```
separate (Common_Navigation_Parts)
package body Update_Velocity is

-- ------------------
-- --local variables-
-- ------------------

   Previous_Velocity : Velocity_Vectors := Initial_Velocity;

pragma PAGE;
   procedure Reinitialize (New_Velocity : in Velocity_Vectors) is

   begin

      Previous_Velocity := New_Velocity;

   end Reinitialize;

pragma PAGE;
   function Update (Nominal_Delta_Velocity : Velocity_Vectors;
                    Coriolis_Acceleration  : Acceleration_Vectors;
                    Delta_Time             : Intervals;
                    Gravity                : Acceleration_Vectors
                                               := Default_Gravity)
                   return Velocity_Vectors is

--    ----------------------------
--    --declaration of variables-
--    ----------------------------

      Current_Velocity  : Velocity_Vectors;
      Temp_A_V          : Acceleration_Vectors;
      Temp_V_V          : Velocity_Vectors;

-- ------------------------------
-- --beginning of function Update
-- ------------------------------

   begin

      Temp_A_V := Sparse_Right_Xy_Subtract(Coriolis_Acceleration, Gravity);
      Temp_V_V := Temp_A_V * Delta_Time;

      Current_Velocity  := Previous_Velocity +
                           Nominal_Delta_Velocity -
                           Temp_V_V;
      Previous_Velocity := Current_Velocity;

      return Current_Velocity;

   end Update;

pragma PAGE;
   function Current_Velocity return Velocity_Vectors is

   begin
```

```
      return Previous_Velocity;
   end Current_Velocity;
end Update_Velocity;
```

```
separate (Common_Navigation_Parts)
function Scalar_Velocity (Velocity_In : Velocity_Vectors)
                                  return Velocities is
begin

   return Vector_Length(Velocity_In);

end Scalar_Velocity;
```

```
separate (Common_Navigation_Parts)
function Compute_Rotation_Increments
            (Platform_Rotation_Rate : Angular_Velocity_Vectors;
             Delta_Time             : Intervals)
            return Angle_Vectors is
begin

   return Platform_Rotation_Rate * Delta_Time;

end Compute_Rotation_Increments;
```

3.3.2.2 NORTH POINTING NAVIGATION PARTS (BODY) TLCSC P003 (CATALOG #P257-0)

This part, which is a package body, contains all the CAMP parts which can be used in a north pointing navigation coordinate system environment.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.2.1 REQUIREMENTS ALLOCATION

The following chart describes the allocation of requirements to the LLCSC's in this TLCSC.

Name	Requirements Allocation
Compute_Coriolis_Acceleration	R008
Radius_of_Curvature	R036
Total_Platform_Rotation_Rates	R012
Earth_Rotation_Rate	R014
Earth_Relative_Rotation_Rates	R026
Latitude_Integration	R027
Longitude_Integration	R031

3.3.2.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.3 INPUT/OUTPUT

None.

3.3.2.2.4 LOCAL DATA

None.

3.3.2.2.5 PROCESS CONTROL

Not applicable.

3.3.2.2.6 PROCESSING

The following describes the processing performed by this part:

```
package body North_Pointing_Navigation_Parts is

end North_Pointing_Navigation_Parts;
```

3.3.2.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.8 LIMITATIONS

None.

3.3.2.2.9 LLCSC DESIGN

3.3.2.2.9.1 RADIUS_OF_CURVATURE PACKAGE DESIGN (CATALOG #P259-0)

This LLCSC contains a function which computes the radius of curvature vector given the current altitude and current latitude.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.2.9.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R036.

3.3.2.2.9.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification of North_Pointing_Navigation.

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Earth_Positions	floating point type	Data type of latitude and longitude values
Distances	floating point type	Data type of distance measurements
Inverse_ Distances	floating point type	Data type of 1/distance measurements
Indices	scalar type	Used to index arrays
Distance_Vectors	array	Array of distances
Real	floating point type	Used to define Earth_Flattening_Coefficient
Sin_Cos_Ratio	floating point type	Data type of results from a sin/cos function

Data objects:

The following table summarizes the generic formal objects required by this part:

Name	Type	Description
Earth_Radius	Distances	Radius of the earth
Earth_Flattening_ Coefficient	Real	Coefficient of earth flattening
One_Over_Earth_ Radius	Inverse_ Distances	Value of 1/radius of the earth

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Defines the operation: Real * Sin_Cos_Ratio := Real
"*"	function	Defines the operation: Distances * Inverse_Distances := Real
"*"	function	Defines the operation: Distances * Real := Distances
"/"	function	Defines the operation: Distances / Real := Distances
Sin_Cos	procedure	Procedure returning the sine and cosine of an input earth position

FORMAL PARAMETERS:

The following table describes the formal parameters to the unit contained in this part:

Name	Type	Mode	Description
Latitude	Earth_Positions	In	Current latitude of the missile
Altitude	Distances	In	Current altitude of the missile

3.3.2.2.9.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
E	Indices	Index to first element in vector
N	Indices	Index to second element in vector
V	Indices	Index to last element in vector

The following table describes the data objects maintained by the unit contained in this package:

Name	Type	Description
Cos_Of_Lat, Sin_Of_Lat	Sin_Cos_Ratio	Cosine and sine of input latitude
Flat_x_Sin_Squared	Sin_Cos_Ratio	Used for intermediate calculations
Long_Demoninator, Short_Denominator	Real	Used for intermediate calculations
Radius_Of_ Curvature	Distance_Vectors	Vector being calculated and returned

3.3.2.2.9.1.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
   package body Radius_of_Curvature is

--    --------------------
--    --local declarations
--    --------------------

      E                   : constant Indices := Indices'FIRST;
      N                   : constant Indices := Indices'SUCC(E);
      V                   : constant Indices := Indices'LAST;
```

```
--    -----------
--    --unit body
--    -----------

      function Compute (Latitude : Earth_Positions;
                        Altitude : Distances)
                       return Distance_Vectors is

--       ---------------------------
--       --declaration of variables-
--       ---------------------------

         Cos_of_Lat          : Sin_Cos_Ratio;
         Flat_x_Sin_Squared  : Real;
         Long_Denominator    : Real;
         Radius_of_Curvature : Distance_Vectors;
         Short_Denominator   : Real;
         Sin_of_Lat          : Sin_Cos_Ratio;

--    ------------------------
--    --begin function Compute
--    ------------------------

      begin

         Sin_Cos(Latitude, Sin_of_Lat, Cos_of_Lat);

         Flat_x_Sin_Squared := Earth_Flattening_Coefficient *
                               (Sin_of_Lat * Sin_of_Lat);

         Short_Denominator := 1.0 -
                              Altitude * One_Over_Earth_Radius -
                              Flat_x_Sin_Squared;

         Long_Denominator  := Short_Denominator +
                              2.0 * Earth_Flattening_Coefficient *
                                (Cos_of_Lat*Cos_of_Lat);

         Radius_of_Curvature(E) := Earth_Radius / Short_Denominator;
         Radius_of_Curvature(N) := Earth_Radius / Long_Denominator;
         Radius_of_Curvature(V) := Earth_Radius * (1.0 - Flat_x_Sin_Squared) +
                                   Altitude;

         return Radius_of_Curvature;

      end Compute;

   end Radius_of_Curvature;
```

3.3.2.2.9.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.9.1.8 LIMITATIONS

None.

3.3.2.2.9.1.9 LLCSC DESIGN

None.

3.3.2.2.9.1.10 UNIT DESIGN

None.

3.3.2.2.9.2 EARTH_ROTATION_RATE PACKAGE DESIGN (CATALOG #P261-0)

This LLCSC contains a function which computes the rotation rate of the Earth given the current latitude.

The calculations performed are as follows:

```
Omega(E) := 0.0
Omega(N) := Earth_Angular_Velocity * cos(Lat)
Omega(U) := Earth_Angular_Velocity * sin(Lat)
```

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.2.9.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R014.

3.3.2.2.9.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification for North_Pointing_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_ Velocities	floating point type	Data type defining angular velocity measurements
Indices	discrete	Index into arrays
Angular_ Velocity_Vectors	array	Array of angular velocities
Earth_Positions	floating point type	Data type defining longitude/latitude measurements
Sin_Cos_Ratio	floating point type	Data type defining results of sin/cos functions

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Earth_Rate	Angular_ Velocities	N/A	Rate of rotation of the earth

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Sin_Cos_Ratio := Angular_Velocities
Sin_Cos	procedure	Returns the sine and cosine of an input earth position

FORMAL PARAMETERS:

The following table describes the formal parameters to the unit in this package:

Name	Type	Mode	Description
Latitude	Earth_Positions	In	Current latitude of the missile

3.3.2.2.9.2.4 LOCAL DATA

Data objects:

wl

The following table describes the data objects maintained by this part:

Name	Type	Description
E, N, U	Indices	Indices into 1st, 2nd, and last elements of vector

The following table describes the data objects maintained local to the unit in this package:

Name	Type	Description
Cos_Of_Lat	Sin_Cos_Ratio	Cosine of input latitude
Rotation_Rate	Angular_Velocity_Vectors	Value being calculated and returned
Sin_Of_Lat	Sin_Cos_Ratio	Sine of input latitude

3.3.2.2.9.2.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
   package body Earth_Rotation_Rate is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      E : constant Indices := Indices'FIRST;
      N : constant Indices := Indices'SUCC(E);
      V : constant Indices := Indices'LAST;


--    -----------
--    --unit body
--    -----------

      function Compute (Latitude : Earth_Positions)
                        return Angular_Velocity_Vectors is

--       ---------------------------
--       --declaration of variables-
--       ---------------------------

         Cos_of_Lat    : Sin_Cos_Ratio;
         Rotation_Rate : Angular_Velocity_Vectors;
         Sin_of_Lat    : Sin_Cos_Ratio;
```

```
--    ------------------------
--    --beginning of function-
--    ------------------------

      begin

         Sin_Cos(Latitude, Sin_of_Lat, Cos_of_Lat);

         Rotation_Rate(E) := 0.0;
         Rotation_Rate(N) := Earth_Rate * Cos_of_Lat;
         Rotation_Rate(V) := Earth_Rate * Sin_of_Lat;

         return Rotation_Rate;

      end Compute;

   end Earth_Rotation_Rate;
```

3.3.2.2.9.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.9.2.8 LIMITATIONS

None.

3.3.2.2.9.2.9 LLCSC DESIGN

None.

3.3.2.2.9.2.10 UNIT DESIGN

None.

3.3.2.2.9.3 EARTH_RELATIVE_NAVIGATION_ROTATION_RATE PACKAGE DESIGN (CATALOG #P262-0)

This package contains a function which computes the rotation rate of the navigation coordinate system with respect to the Earth.

The calculations performed are as follows:

```
Rho(E) := - Vel(N) / Radius_of_Curvature(N)
Rho(N) :=   Vel(E) / Radius_of_Curvature(E)
Rho(V) :=   Rho(N) * tan(lat)
```

where Vel = the missile's current velocity
Lat = latitude of the missile

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.2.9.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R026.

3.3.2.2.9.3.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification of North_Pointing_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Indices	floating point type	Used to dimension imported vector types
Angular_Velocities	floating point type	Data type of angular velocity objects
Angular_Velocity_Vectors	array	Array of angular velocities
Distances	floating point type	Data type of distance measurements
Distance_Vectors	array	Array of distances
Earth_Positions	floating point type	Data type of longitude/latitude objects
Tan_Ratio	floating point type	Data type of results of tangent function
Velocities	floating point type	Data type of velocity measurements
Velocity_Vectors	array	Array of velocities

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Tan_Ratio := Angular_Velocities
"/"	function	Division operator defining the operation: Velocities / Distances := Angular_Velocities
Tan	function	Tangent function

FORMAL PARAMETERS:

The following table describes the formal parameters to the unit contained in this part:

Name	Type	Mode	Description
Missile_Velocity	Velocity_Vectors	In	Missile's current velocity vector
Radius_of_Curvature	Distance_Vectors	In	East and north components of the radius of curvature
Latitude	Earth_Positions	In	Current latitude of the missile

3.3.2.2.9.3.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
E, N, U	Indices	Indices into 1st, 2nd, and last positions of a vector

The following table describes the data objects maintained local to the unit contained in this part:

Name	Type	Description
Rho	Angular_Velocity_Vectors	Vector being calculated and returned

3.3.2.2.9.3.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.3.6 PROCESSING

The following describes the processing performed by this part:

```
   package body Earth_Relative_Navigation_Rotation_Rate is

--    ----------------------------
--    --declaration of variables-
--    ----------------------------
```

```
      E   : constant Indices := Indices'FIRST;
      N   : constant Indices := Indices'SUCC(E);
      V   : constant Indices := Indices'LAST;


--    -----------
--    --unit body
--    -----------

      function Compute (Missile_Velocity    : Velocity_Vectors;
                        Radius_of_Curvature : Distance_Vectors;
                        Latitude            : Earth_Positions)
                       return Angular_Velocity_Vectors is

--       --------------------------
--       --declaration of variables-
--       --------------------------

         Rho : Angular_Velocity_Vectors;

--    ------------------------
--    --beginning of function-
--    ------------------------

      begin

         Rho(e) := - Missile_Velocity(n) / Radius_of_Curvature(n);
         Rho(n) := Missile_Velocity(e) / Radius_of_Curvature(e);
         Rho(v) := Rho(n) * Tan(Latitude);

         return Rho;

      end Compute;

   end Earth_Relative_Navigation_Rotation_Rate;
```

3.3.2.2.9.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.9.3.8 LIMITATIONS

None.

3.3.2.2.9.3.9 LLCSC DESIGN

None.

3.3.2.2.9.3.10 UNIT DESIGN

None.

3.3.2.2.9.4 LATITUDE INTEGRATION PACKAGE DESIGN (CATALOG #P263-0)

This LLCSC, which is a package, calculates the missile's current latitude using trapezoidal integration of the east component of the Earth-relative rotation rate of the navigation coordinate system. This part can be used when a north pointing, local level coordinate system is being used for navigation.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.2.9.4.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R027.

3.3.2.2.9.4.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.4.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Previously defined in package specification for North_Pointing_Navigation_-Parts.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	Data type of angular velocity objects
Earth_Positions	floating point type	Data type of latitude and longitude values
Intervals	floating point type	Data type of time values

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Default_Delta	Intervals	N/A	Default time over which integration is to take place
Initial_East_Rho	Angular_Velocities	N/A	Initial value of the East component of earth-relative rotation
Initial_Latitude	Earth_Position	N/A	Initial value of the latitude

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Intervals := Earth_Positions

3.3.2.2.9.4.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained local to this part:

Name	Type	Value	Description
Previous_East_Rho	Angular_Velocities	N/A	Previous value of the East component of the Earth-relative rotation
Previous_Latitude	Earth_Positions	N/A	Previous value of the latitude

3.3.2.2.9.4.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.4.6 PROCESSING

The following describes the processing performed by this part:

```
   package body Latitude_Integration is

--    --------------------
--    --local declarations
--    --------------------

      Previous_East_Rho : Angular_Velocities := Initial_East_Rho;
      Previous_Latitude : Earth_Positions    := Initial_Latitude;

   end Latitude_Integration;
```

3.3.2.2.9.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.9.4.8 LIMITATIONS

None.

3.3.2.2.9.4.9 LLCSC DESIGN

None.

3.3.2.2.9.4.10 UNIT DESIGN

3.3.2.2.9.4.10.1 REINITIALIZE UNIT DESIGN

This unit, which is a procedure, reinitializes the previous values of the east component of the earth-relative rotation and latitude.

3.3.2.2.9.4.10.1.1 REQUIREMENTS ALLOCATION

This unit partially meets CAMP requirement R027.

3.3.2.2.9.4.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.4.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
East_Rho	Angular_Velocities	In	Initial value for previous_east_rho
Latitude	Earth_Positions	In	Initial value for previous_latitude

3.3.2.2.9.4.10.1.4 LOCAL DATA

None.

3.3.2.2.9.4.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.4.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Reinitialize (East_Rho : in Angular_Velocities;
                        Latitude : in Earth_Positions) is

begin

   Previous_East_Rho := East_Rho;
   Previous_Latitude := Latitude;

end Reinitialize;
```

3.3.2.2.9.4.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic formal types in the package specification for Latitude_Integration:

Name	Type	Description
Angular_ Velocities	floating point type	Data type of angular velocity objects
Earth_Positions	floating point type	Data type of latitude and longitude values
Intervals	floating point type	Data type of time values

Data objects:

The following table describes the data objects required by this part and maintained local to the Latitude_Integration package.

Name	Type	Value	Description
Previous_ East_Rho	Angular_ Velocities	N/A	Previous value of the East component of the Earth-relative rotation
Previous_ Latitude	Earth_ Positions	N/A	Previous value of the latitude

3.3.2.2.9.4.10.1.8 LIMITATIONS

None.

3.3.2.2.9.4.10.2 INTEGRATE UNIT DESIGN

This unit, which is a function, calculates a new latitude through trapezoidal integration.

3.3.2.2.9.4.10.2.1 REQUIREMENTS ALLOCATION

This unit partially meets CAMP requirement R027.

3.3.2.2.9.4.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.4.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
East_Rho	Angular_Velocities	In	Current value of the east component of the earth-relative rotation rate of the navigation coordinate system
Delta_Time	Intervals	In	Time interval over which the integration is to take place

3.3.2.2.9.4.10.2.4 LOCAL DATA

None.

3.3.2.2.9.4.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.4.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
function Integrate (East_Rho   : Angular_Velocities;
                    Delta_Time : Intervals := Default_Delta_Time)
                   return Earth_Positions is
```

```
      Latitude : Earth_Positions;

   begin

      Latitude := Previous_Latitude +
                  ((East_Rho - Previous_East_Rho) * (0.5 * Delta_Time) );

      Previous_Latitude := Latitude;
      Previous_East_Rho := East_Rho;

      return Latitude;

   end Integrate;
```

3.3.2.2.9.4.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic formal types in the package specification for Latitude_Integration:

Name	Type	Description
Angular_Velocities	floating point type	Data type of angular velocity objects
Earth_Positions	floating point type	Data type of latitude and longitude values
Intervals	floating point type	Data type of time values

Data objects:

The following table describes the data objects required by this part and maintained local to the Latitude_Integration package.

Name	Type	Value	Description
Previous_East_Rho	Angular_Velocities	N/A	Previous value of the East component of the Earth-relative rotation
Previous_Latitude	Earth_Positions	N/A	Previous value of the latitude

Subprograms and task entries:

The following describes the subprograms required by this part and defined as generic formal subprograms to the Latitude_Integration package:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Intervals := Earth_Positions

3.3.2.2.9.4.10.2.8 LIMITATIONS

None.

3.3.2.2.9.5 LONGITUDE INTEGRATION PACKAGE DESIGN (CATALOG #P264-0)

This LLCSC, which is a package, calculates the missile's current longitude using trapezoidal integration. This part can be used when a north pointing local level coordinate system is being used for navigation.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.2.9.5.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R031.

3.3.2.2.9.5.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.5.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Previously defined in package specification for North_Pointing_Navigation_Parts

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	Data type of angular velocity objects
Earth_Positions	floating point type	Data type of latitude/longitude values
Intervals	floating point type	Data type of time values
Sin_Cos_Ratio	floating point type	Data type of values return by sin/cos functions

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Default_Delta	Intervals	N/A	Default time over which integration is to take place
Initial_North_Rho	Angular_Velocities	N/A	Initial value of the North component of the earth-relative rotation rate of the navigation coordinate system
Initial_Latitude	Earth_Positions	N/A	Initial value of the latitude
Initial_Longitude	Earth_Positions	N/A	Initial value of the longitude

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"/"	function	Division operator defining the operation: Angular_Velocities / Sin_Cos_Ratio := Angular_Velocities
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Intervals := Earth_Positions
Cos	function	Cosine function

3.3.2.2.9.5.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained local to this part:

Name	Type	Description
Previous_Integration_Variable	Angular_Velocities	Previous value of the integration variable
Previous_Longitude	Earth_Positions	Previous longitude value .

3.3.2.2.9.5.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.5.6 PROCESSING

The following describes the processing performed by this part:

```
   package body Longitude_Integration is

--    ------------------
--    --local variables-
--    ------------------

      Previous_Integration_Variable : Angular_Velocities
                                      := Initial_North_Rho /
                                         Cos(Initial_Latitude);

      Previous_Longitude            : Earth_Positions := Initial_Longitude;

   end Longitude_Integration;
```

3.3.2.2.9.5.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.9.5.8 LIMITATIONS

None.

3.3.2.2.9.5.9 LLCSC DESIGN

None.

3.3.2.2.9.5.10 UNIT DESIGN

3.3.2.2.9.5.10.1 REINITIALIZE UNIT DESIGN

This unit, which is a procedure, reinitializes the previous integration variable and the previous longitude.

3.3.2.2.9.5.10.1.1 REQUIREMENTS ALLOCATION

This part partially meets CAMP requirement R031.

3.3.2.2.9.5.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.5.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
North_Rho	Angular_ Velocities	In	Initial value of the North component of the earth-relative rotation rate of the navigation coordinate system
Latitude	Earth_Positions	In	Initial value of the latitude
Longitude	Earth_Positions	In	Initial value of the longitude

3.3.2.2.9.5.10.1.4 LOCAL DATA

None.

3.3.2.2.9.5.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.5.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Reinitialize (North_rho : in Angular_Velocities;
                        Latitude  : in Earth_Positions;
                        Longitude : in Earth_Positions) is

begin

   Previous_Integration_Variable := North_Rho / Cos(Latitude);
   Previous_Longitude            := Longitude;

end Reinitialize;
```

3.3.2.2.9.5.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic formal parameters to the Longitude_Integration package:

Name	Type	Description
Angular_Velocities	floating point type	Data type of angular velocity objects
Earth_Positions	floating point type	Data type of latitude/longitude values
Sin_Cos_Ratio	floating point type	Data type of values return by sin/cos functions

Data objects:

The following objects are required by this part and maintained in the package body of Longitude_Integration:

Name	Type	Description
Previous_Integration_Variable	Angular_Velocities	Previous value of the integration variable
Previous_Longitude	Earth_Positions	Previous longitude value

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined as generic formal parameters to the Longitude_Integration package:

Name	Type	Description
"/"	function	Division operator defining the operation: Angular_Velocities / Sin_Cos_Ratio := Angular_Velocities
Cos	function	Cosine function

3.3.2.2.9.5.10.1.8 LIMITATIONS

None.

3.3.2.2.9.5.10.2 INTEGRATE UNIT DESIGN

This unit, which is a function, calculates the new longitude using trapezoidal integration.

3.3.2.2.9.5.10.2.1 REQUIREMENTS ALLOCATION

This unit partially meets CAMP requirement R031.

3.3.2.2.9.5.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.9.5.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
North_Rho	Angular_Velocities	In	Current value of the North component of the earth-relative rotation rate of the navigation coordinate system
Latitude	Earth_Positions	In	Current latitude
Delta_Time	Intervals	In	Time interval over which the integration is to take place

3.3.2.2.9.5.10.2.4 LOCAL DATA

Data objects:

The following table describes the local data maintained by this part:

Name	Type	Value	Description
Longitude	Earth_Positions	N/A	Longitude being calculated
Temp_PIV	Angular_Velocities	N/A	Temporary previous integration variable

3.3.2.2.9.5.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.2.9.5.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
      function Integrate (North_Rho  : Angular_Velocities;
                          Latitude   : Earth_Positions;
                          Delta_Time : Intervals := Default_Delta_Time)
                         return Earth_Positions is

--       --------------------------
--       --declaration of variables-
--       --------------------------
```

```
            Longitude : Earth_Positions;
            Temp_PIV  : Angular_Velocities;

--      -------------------------
--      --begin function Integrate
--      -------------------------

      begin

         Temp_PIV  := North_Rho / Cos(Latitude);

         Longitude := Previous_Longitude +
                      ((Temp_PIV - Previous_Integration_Variable) *
                       (0.5 * Delta_Time));

         Previous_Integration_Variable := Temp_PIV;
         Previous_Longitude            := Longitude;

         return Longitude;

      end Integrate;
```

3.3.2.2.9.5.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF ANCESTRAL ELEMENTS:

The following tables describe the elements used by this part but defined in one or more ancestral units:

Data types:

The following table summarizes the types required by this part and defined as generic formal parameters to the Longitude_Integration package:

Name	Type	Description
Angular_ Velocities	floating point type	Data type of angular velocity objects
Earth_Positions	floating point type	Data type of latitude/longitude values
Intervals	floating point type	Data type of time values
Sin_Cos_Ratio	floating point type	Data type of values return by sin/cos functions

Data objects:

The following objects are required by this part and maintained in the package body of Longitude_Integration:

Name	Type	Description
Previous_Integration_Variable	Angular_Velocities	Previous value of the integration variable
Previous_Longitude	Earth_Positions	Previous longitude value

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined as generic formal parameters to the Longitude_Integration package:

Name	Type	Description
"/"	function	Division operator defining the operation: Angular_Velocities / Sin_Cos_Ratio := Angular_Velocities
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Intervals := Earth_Positions
Cos	function	Cosine function

3.3.2.2.9.5.10.2.8 LIMITATIONS

None.

3.3.2.2.10 UNIT DESIGN

3.3.2.2.10.1 COMPUTE CORIOLIS ACCELERATION UNIT DESIGN (CATALOG #P258-0)

This function computes the components of the coriolis acceleration vector when a local level, north pointing coordinate system is being used for navigation.

The calculations performed are as follows:

CA := (2 * Omega_Vector + Rho_Vector) x Velocity_Vector

3.3.2.2.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R008.

3.3.2.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in package specificatic . for North_Pointing_Navigation_Parts.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Velocity_Vectors	private	Array of velocities
Angular_Velocity_ Vectors	private	Array of angular velocities
Acceleration_Vectors	private	Array of accelerations

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Sparse_Right_X_Add	function	Defines the way two angular velocity vectors are added when the first component in the second vector equals 0
Cross_Product	function	Performs a cross product operation between an angular velocity vector and a velocity vector, resulting in an acceleration vector

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Velocity_In	Velocity_Vectors	In	Contains the E, N, and U components of the missile's velocity
Rho_In	Angular_Velocity_ Vectors	In	Contains the E, N, and U components of the missile's velocity
Omega_In	Angular_Velocity_ Vectors	In	Contains the N and U components of the current earth's rotation rate

3.3.2.2.10.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Coriolis_Acceleration	Acceleration_Vectors	This is the value being calculated and returned
Temp_AVV	Angular_Velocity_Vectors	Temporary angular velocity vector used for intermediate calculations

3.3.2.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
   function Compute_Coriolis_Acceleration
              (Velocity_In : Velocity_Vectors;
               Rho_In      : Angular_Velocity_Vectors;
               Omega_In    : Angular_Velocity_Vectors)
              return Acceleration_Vectors is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      Coriolis_Acceleration : Acceleration_Vectors;
      Temp_AVV              : Angular_Velocity_Vectors;

-- ------------------------
-- --beginning of function-
-- ------------------------

   begin

      Temp_AVV              := Sparse_Right_X_Add(Omega_In, Omega_In);
      Temp_AVV              := Sparse_Right_X_Add(Rho_In, Temp_AVV);
      Coriolis_Acceleration := Cross_Product(Temp_AVV, Velocity_In);

      return Coriolis_Acceleration;

   end Compute_Coriolis_Acceleration;
```

3.3.2.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.10.1.8 LIMITATIONS

None.

3.3.2.2.10.2 TOTAL_PLATFORM_ROTATION_RATES UNIT DESIGN (CATALOG #P260-0)

This function computes the rotation rate of the navigation coordinate system with respect to inertial space.

The calculations performed are as follows:

```
TPR := Rho_Vector + Omega_Vector
```

3.3.2.2.10.2.1 REQUIREMENTS ALLOCATION

See top header.

3.3.2.2.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.2.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined when this part was specified.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocity_Vectors	private	Array of angular velocities

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Sparse_Right_X_Add	function	Adds two angular velocity vectors assuming the x-component of the right vector equals 0.0

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Rho_Vector	Angular_Velocity_Vectors	In	Rotation rate vector of the navigation coordinate system with respect to the earth
Omega_Vector	Angular_Velocity_Vectors	In	Earth's rotation rate vector

3.3.2.2.10.2.4 LOCAL DATA

None.

3.3.2.2.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.2.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
function Total_Platform_Rotation_Rates
            (Rho_Vector   : Angular_Velocity_Vectors;
             Omega_Vector : Angular_Velocity_Vectors)
            return Angular_Velocity_Vectors is
begin
   return Sparse_Right_X_Add (Left  => Rho_Vector,
                              Right => Omega_Vector);
end Total_Platform_Rotation_Rates;
```

3.3.2.2.10.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.2.10.2.8 LIMITATIONS

None.

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```
package body North_Pointing_Navigation_Parts is

pragma PAGE;
   function Compute_Coriolis_Acceleration
              (Velocity_In : Velocity_Vectors;
               Rho_In      : Angular_Velocity_Vectors;
               Omega_In    : Angular_Velocity_Vectors)
              return Acceleration_Vectors is

--     ---------------------------
--     --declaration of variables-
--     ---------------------------

      Coriolis_Acceleration : Acceleration_Vectors;
      Temp_Avv              : Angular_Velocity_Vectors;

-- ------------------------
-- --beginning of function-
-- ------------------------

   begin

      Temp_Avv              := Sparse_Right_X_Add(Omega_In, Omega_In);
      Temp_Avv              := Sparse_Right_X_Add(Rho_In, Temp_Avv);
      Coriolis_Acceleration := Cross_Product(Temp_Avv, Velocity_In);

      return Coriolis_Acceleration;

   end Compute_Coriolis_Acceleration;

pragma PAGE;
   package body Radius_Of_Curvature is

--     --------------------
--     --local declarations
--     --------------------

      E                     : constant Indices := Indices'FIRST;
      N                     : constant Indices := Indices'SUCC(E);
      V                     : constant Indices := Indices'LAST;

pragma PAGE;
--     -----------
--     --unit body
--     -----------

      function Compute (Latitude : Earth_Positions;
                        Altitude : Distances)
                       return Distance_Vectors is

--        ---------------------------
--        --declaration of variables-
--        ---------------------------

          Cos_Of_Lat          : Sin_Cos_Ratio;
          Flat_X_Sin_Squared  : Real;
          Long_Denominator    : Real;
```

```
         Radius_Of_Curvature : Distance_Vectors;
         Short_Denominator   : Real;
         Sin_Of_Lat          : Sin_Cos_Ratio;

--    -------------------------
--    --begin function Compute
--    -------------------------

      begin

         Sin_Cos(Latitude, Sin_Of_Lat, Cos_Of_Lat);

         Flat_X_Sin_Squared := Earth_Flattening_Coefficient *
                               (Sin_Of_Lat * Sin_Of_Lat);

         Short_Denominator := 1.0 -
                              Altitude * One_Over_Earth_Radius -
                              Flat_X_Sin_Squared;

         Long_Denominator  := Short_Denominator +
                              2.0 * Earth_Flattening_Coefficient *
                                (Cos_Of_Lat*Cos_Of_Lat);

         Radius_Of_Curvature(E) := Earth_Radius / Short_Denominator;
         Radius_Of_Curvature(N) := Earth_Radius / Long_Denominator;
         Radius_Of_Curvature(V) := Earth_Radius * (1.0 - Flat_X_Sin_Squared) +
                                   Altitude;

         return Radius_Of_Curvature;

      end Compute;

   end Radius_Of_Curvature;

pragma PAGE;
   function Total_Platform_Rotation_Rates
               (Rho_Vector   : Angular_Velocity_Vectors;
                Omega_Vector : Angular_Velocity_Vectors)
               return Angular_Velocity_Vectors is
   begin
      return Sparse_Right_X_Add (Left  => Rho_Vector,
                                 Right => Omega_Vector);
   end Total_Platform_Rotation_Rates;

pragma PAGE;
   package body Earth_Rotation_Rate is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      E : constant Indices := Indices'FIRST;
      N : constant Indices := Indices'SUCC(E);
      V : constant Indices := Indices'LAST;

pragma PAGE;
--    -----------
```

```
--     --unit body
--     -----------

       function Compute (Latitude : Earth_Positions)
                         return Angular_Velocity_Vectors is

--        ---------------------------
--        --declaration of variables-
--        ---------------------------

          Cos_Of_Lat    : Sin_Cos_Ratio;
          Rotation_Rate : Angular_Velocity_Vectors;
          Sin_Of_Lat    : Sin_Cos_Ratio;

--     ------------------------
--     --beginning of function-
--     ------------------------

       begin

          Sin_Cos(Latitude, Sin_Of_Lat, Cos_Of_Lat);

          Rotation_Rate(E) := 0.0;
          Rotation_Rate(N) := Earth_Rate * Cos_Of_Lat;
          Rotation_Rate(V) := Earth_Rate * Sin_Of_Lat;

          return Rotation_Rate;

       end Compute;

   end Earth_Rotation_Rate;

pragma PAGE;
   package body Earth_Relative_Navigation_Rotation_Rate is

--     ---------------------------
--     --declaration of variables-
--     ---------------------------

       E   : constant Indices := Indices'FIRST;
       N   : constant Indices := Indices'SUCC(E);
       V   : constant Indices := Indices'LAST;

pragma PAGE;
--     -----------
--     --unit body
--     -----------

       function Compute (Missile_Velocity    : Velocity_Vectors;
                         Radius_Of_Curvature : Distance_Vectors;
                         Latitude            : Earth_Positions)
                        return Angular_Velocity_Vectors is

--        ---------------------------
--        --declaration of variables-
--        ---------------------------
```

```
         Rho : Angular_Velocity_Vectors;

--       ------------------------
--       --beginning of function-
--       ------------------------

      begin

         Rho(E) := - Missile_Velocity(N) / Radius_Of_Curvature(N);
         Rho(N) := Missile_Velocity(E) / Radius_Of_Curvature(E);
         Rho(V) := Rho(N) * Tan(Latitude);

         return Rho;

      end Compute;

   end Earth_Relative_Navigation_Rotation_Rate;

pragma PAGE;
   package body Latitude_Integration is

--       --------------------
--       --local declarations
--       --------------------

      Previous_East_Rho : Angular_Velocities := Initial_East_Rho;
      Previous_Latitude : Earth_Positions    := Initial_Latitude;

pragma PAGE;
      procedure Reinitialize (East_Rho : in Angular_Velocities;
                              Latitude : in Earth_Positions) is

      begin

         Previous_East_Rho := East_Rho;
         Previous_Latitude := Latitude;

      end Reinitialize;

pragma PAGE;
      function Integrate (East_Rho   : Angular_Velocities;
                          Delta_Time : Intervals := Default_Delta_Time)
                         return Earth_Positions is

         Latitude : Earth_Positions;

      begin

         Latitude := Previous_Latitude +
                     ((East_Rho - Previous_East_Rho) * (0.5 * Delta_Time) );

         Previous_Latitude := Latitude;
         Previous_East_Rho := East_Rho;

         return Latitude;

      end Integrate;
```

```
   end Latitude_Integration;

pragma PAGE;
   package body Longitude_Integration is

--    ------------------
--    --local variables-
--    ------------------

      Previous_Integration_Variable : Angular_Velocities
                                    := Initial_North_Rho /
                                       Cos(Initial_Latitude);

      Previous_Longitude            : Earth_Positions := Initial_Longitude;

pragma PAGE;
      procedure Reinitialize (North_Rho : in Angular_Velocities;
                              Latitude  : in Earth_Positions;
                              Longitude : in Earth_Positions) is

      begin

         Previous_Integration_Variable := North_Rho / Cos(Latitude);
         Previous_Longitude            := Longitude;

      end Reinitialize;

pragma PAGE;
      function Integrate (North_Rho  : Angular_Velocities;
                          Latitude   : Earth_Positions;
                          Delta_Time : Intervals := Default_Delta_Time)
                         return Earth_Positions is

--       --------------------------
--       --declaration of variables-
--       --------------------------

           Longitude : Earth_Positions;
           Temp_Piv  : Angular_Velocities;

--    --------------------------
--    --begin function Integrate
--    --------------------------

      begin

         Temp_Piv  := North_Rho / Cos(Latitude);

         Longitude := Previous_Longitude +
                      ((Temp_Piv - Previous_Integration_Variable) *
                       (0.5 * Delta_Time));

         Previous_Integration_Variable := Temp_Piv;
         Previous_Longitude            := Longitude;

         return Longitude;
```

```
      end Integrate;
   end Longitude_Integration;
end North_Pointing_Navigation_Parts;
```

3.3.2.3 WANDER_AZIMUTH_NAVIGATION_PARTS (PACKAGE BODY) TLCSC P002 (CATALOG #P234-0)

This package contairs the specifications for all parts which can be used in a Wander Azimuth navigation coordinate system environment.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.3.1 REQUIREMENTS ALLOCATION

The following chart summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
Compute_East_Velocity	R185
Compute_North_Velocity	R186
Compute_Earth_Relative_Horizontal_Velocities	R001
Compute_Total_Angular_Velocity	R004
Compute_Coriolis_Acceleration	R007
Coriolis_Acceleration_From_Total_Rates	R187
Radius_of_Curvature	R035
Total_Platform_Rotation_Rate	R011
Earth_Rotation_Rate	R013
Earth_Relative_Rotation_Rate	R025
Latitude	R029
Compute_Latitude_using_Arctangent	R030
Compute_Longitude	R033
Compute_Wander_Azimuth_Angle	R028

3.3.2.3.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.3 INPUT/OUTPUT

None.

3.3.2.3.4 LOCAL DATA

None.

3.3.2.3.5 PROCESS CONTROL

Not applicable.

3.3.2.3.6 PROCESSING

The following describes the processing performed by this part:

```
package body Wander_Azimuth_Navigation_Parts is

   function Compute_East_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles)
            return Velocities is separate;

   function Compute_East_Velocity_with_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_of_Wander_Angle : Sin_Cos_Ratio)
            return Velocities is separate;

   function Compute_North_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles)
            return Velocities is separate;

   function Compute_North_Velocity_with_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_of_Wander_Angle : Sin_Cos_Ratio)
            return Velocities is separate;

   procedure Compute_Earth_Relative_Horizontal_Velocities
             (Nominal_East_Velocity  : in  Velocities;
              Nominal_North_Velocity : in  Velocities;
              Current_Wander_Angle   : in  Wander_Angles;
              East_Velocity          : out Velocities;
              North_Velocity         : out Velocities)
             is separate;

   procedure Compute_Earth_Relative_Horizontal_Velocities_with_Sin_Cos_In
             (Nominal_East_Velocity  : in     Velocities;
              Nominal_North_Velocity : in     Velocities;
              Sine_of_Wander_Angle   : in     Sin_Cos_Ratio;
              Cosine_of_Wander_Angle : in     Sin_Cos_Ratio;
              East_Velocity          :    out Velocities;
              North_Velocity         :    out Velocities)
             is separate;

   function Compute_Total_Angular_Velocity
            (Rho_East  : Angular_Velocities;
             Rho_North : Angular_Velocities)
            return Angular_Velocities is separate;

   function Compute_Coriolis_Acceleration
            (Velocity_in : Velocity_Vectors;
             Rho_in      : Angular_Velocity_Vectors;
```

```
                Omega_in    : Angular_Velocity_Vectors)
              return Acceleration_Vectors is separate;

    package body Coriolis_Acceleration_From_Total_Rates is separate;

    function Compute_Curvatures
              (DC_P_V          : Direction_Cosine_Matrix_Elements;
               DC_P_NE         : Direction_Cosine_Matrix_Elements;
               DC_P_NN         : Direction_Cosine_Matrix_Elements;
               Current_Altitude : Distances)
              return Inverse_Distance_Vectors is separate;

    function Total_Platform_Rotation_Rate
              (Rho_Vector   : Angular_Velocity_Vectors;
               Omega_Vector : Angular_Velocity_Vectors)
              return Angular_Velocity_Vectors is separate;

    package body Earth_Rotation_Rate is separate;

    function Compute_Earth_Relative_Navigation_Rotation_Rate
              (Missile_Velocity    : Velocity_Vectors;
               Curvatures          : Inverse_Distance_Vectors)
              return Angular_Velocity_Vectors is separate;

    function Compute_Latitude (Sin_Latitude : Sin_Cos_Ratio)
                              return Earth_Positions is separate;

    function Compute_Latitude_using_Arctangent
              (DC_P_V  : Direction_Cosine_Matrix_Elements;
               DC_P_NE : Direction_Cosine_Matrix_Elements;
               DC_P_NN : Direction_Cosine_Matrix_Elements)
              return Earth_Positions is separate;

    function Compute_Latitude_using_Two_Value_Arctangent
              (DC_P_V  : Direction_Cosine_Matrix_Elements;
               DC_P_NE : Direction_Cosine_Matrix_Elements;
               DC_P_NN : Direction_Cosine_Matrix_Elements)
              return Earth_Positions is separate;

    function Compute_Longitude
              (DC_R_V : Direction_Cosine_Matrix_Elements;
               DC_G_V : Direction_Cosine_Matrix_Elements)
              return Earth_Positions is separate;

    function Compute_Longitude_using_Two_Value_Arctangent
              (DC_R_V : Direction_Cosine_Matrix_Elements;
               DC_G_V : Direction_Cosine_Matrix_Elements)
              return Earth_Positions is separate;

    function Compute_Wander_Azimuth_Angle
              (DC_P_NE : Direction_Cosine_Matrix_Elements;
               DC_P_NN : Direction_Cosine_Matrix_Elements)
              return Wander_Angles is separate;

    function Compute_Wander_Azimuth_Angle_using_Two_Value_Arctangent
              (DC_P_NE : Direction_Cosine_Matrix_Elements;
               DC_P_NN : Direction_Cosine_Matrix_Elements)
```

```
            return Wander_Angles is separate;

end Wander_Azimuth_Navigation_Parts;
```

3.3.2.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.8 LIMITATIONS

None.

3.3.2.3.9 LLCSC DESIGN

3.3.2.3.9.1 CORIOLIS_ACCELERATION_FROM_TOTAL_RATES PACKAGE DESIGN (CATALOG #P240-0)

This package contains a function which computes the Coriolis acceleration given the velocity vector, Rho vector, and Total Rates vector.

The computations are performed as follows:

(2 * Omega Vector + Rho Vector) x Velocity Vector

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.3.9.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R187.

3.3.2.3.9.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters for this part were previously defined in the package specification of Wander_Azimuth_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Acceleration_Vectors	private	Array of acceleration measurements
Angular_Velocities	floating point type	Data type defining angular velocity measurements
Indices	discrete type	Used to dimension Angular_Velocity_Vectors
Angular_Velocity_Vectors	array	Array of angular velocities
Velocity_Vectors	private	Array of velocity measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Cross_Product	function	Cross product function performing a cross product operation on Angular_Velocity_Vectors and Velocity_Vectors to obtain Acceleration_Vectors

FORMAL PARAMETERS:

The following table describes the formal parameters to the unit contained in this part:

Name	Type	Mode	Description
Velocity_in	Velocity_Vectors	In	Contains the nominal East, North and vertical components of the missile's velocity
Omega	Angular_Velocity_Vectors	In	Contains the nominal East, North and vertical components of the missile's velocity
Total_Rates	Angular_Velocity_Vectors	In	Contains the nominal East, North and vertical components of the total platform rate

3.3.2.3.9.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
E	Indices	Indices'FIRST	Index into first element of array
N	Indices	Indices'SUCC(E)	Index into second element of array
U	Indices	Indices'LAST	Index into last element of array

The following table describes the data objects maintained by the unit contained in this part:

Name	Type	Value	Description
Temp_A_V_V	Angular_ Velocity_ Vectors	N/A	Temporary angular velocity vector

3.3.2.3.9.1.5 PROCESS CONTROL

Not applicable.

3.3.2.3.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
package body Coriolis_Acceleration_from_Total_Rates is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   E               : constant Indices := Indices'FIRST;
   N               : constant Indices := Indices'SUCC(E);
   U               : constant Indices := Indices'LAST;


-- ------------
-- --unit body-
-- ------------

   function Compute (Velocity_In : Velocity_Vectors;
                     Omega       : Angular_Velocity_Vectors;
                     Total_Rates : Angular_Velocity_Vectors)
                    return Acceleration_Vectors is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      Temp_A_V_V      : Angular_Velocity_Vectors;

-- ---------------------------
```

```
-- --begin function Compute
-- ------------------------

   begin

      Temp_A_V_V(E) := Omega(E) + Total_Rates(E);
      Temp_A_V_V(N) := Omega(N) + Total_Rates(N);
      Temp_A_V_V(U) := Omega(U) + Omega(U);

      return Cross_Product(Temp_A_V_V, Velocity_In);

   end Compute;

end Coriolis_Acceleration_From_Total_Rates;
```

3.3.2.3.9.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.9.1.8 LIMITATIONS

None.

3.3.2.3.9.1.9 LLCSC DESIGN

None.

3.3.2.3.9.1.10 UNIT DESIGN

None.

3.3.2.3.9.2 EARTH_ROTATION_RATE PACKAGE DESIGN (CATALOG #P243-0)

This package contains a function which computes the rotation rate of the Earth given some elements of the Direction Cosine matrix.

The computations are performed as follows:

Omega(i) := Direction Cosine Matrix(P,i) * Earth's rotation rate

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.3.9.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R013.

3.3.2.3.9.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification of Wander_Azimuth_Navigation_Parts:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	Data type defining angular velocity measurements
Indices	discrete type	Used to dimension angular_velocity_vector
Angular_Velocity_Vectors	array	Array of angular velocities dimensioned by Indices type
Direction_Cosine_Matrix_Elements	floating point type	Used to define elements of the direction cosine matrix

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Earth_Rate	Angular_Velocities	N/A	Rotation rate of the Earth

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Direction_Cosine_Matrix_Elements * Angular_Velocities => Angular_Velocities

FORMAL PARAMETERS:

The following table describes the formal parameters to the unit in this part:

Name	Type	Mode	Description
DC_P_V	Direction_Cosine_Matrix_Elements	In	Sine of the current latitude of the missile
DC_P_NE	Direction_Cosine_Matrix_Elements	In	Product of the sine of the wander angle and the cosine of the latitude
DC_P_NN	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the wander angle and the cosine of the latitude

3.3.2.3.9.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
NE	Indices	Indices'FIRST	Index into first element of array
NN	Indices	Indices 'SUCC(NE)	Index into second element of array
V	Indices	Indices'LAST	Index into third element of array

The following table describes the data objects maintain by the unit in this part:

Name	Type	Value	Description
Rotation_Rate	Angular_Velocity_Vectors	N/A	Vector being calculated and returned

3.3.2.3.9.2.5 PROCESS CONTROL

Not applicable.

3.3.2.3.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
package body Earth_Rotation_Rate is

-- --------------------
-- --local declarations
```

```
-- --------------------

   NE             : constant Indices := Indices'FIRST;
   NN             : constant Indices := Indices'SUCC(NE);
   V              : constant Indices := Indices'LAST;


-- ------------
-- --unit body-
-- ------------

   function Compute (DC_P_V  : Direction_Cosine_Matrix_Elements;
                     DC_P_NE : Direction_Cosine_Matrix_Elements;
                     DC_P_NN : Direction_Cosine_Matrix_Elements)
                    return Angular_Velocity_Vectors is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      Rotation_Rate : Angular_Velocity_Vectors;

-- ------------------------
-- --beginning of function-
-- ------------------------

   begin

      Rotation_Rate(NE) := DC_P_NE * Earth_Rate;
      Rotation_Rate(NN) := DC_P_NN * Earth_Rate;
      Rotation_Rate(V)  := DC_P_V * Earth_Rate;

      return Rotation_Rate;

   end Compute;

end Earth_Rotation_Rate;
```

3.3.2.3.9.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.9.2.8 LIMITATIONS

None.

3.3.2.3.9.2.9 LLCSC DESIGN

None.

3.3.2.3.9.2.10 UNIT DESIGN

None.

3.3.2.3.10 UNIT DESIGN

3.3.2.3.10.1 COMPUTE_EAST_VELOCITY UNIT DESIGN (CATALOG #P235-0)

This function computes the east velocity given the nominal east and north velocities and the wander angle.

The computations are performed as follows:

```
VelE := VelNE * Cos(WA) - VelNN * Sin(WA)

where VelNE = nominal east velocity
      VelNN = nominal north velocity
      WA    = wander angle
```

3.3.2.3.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R158.

3.3.2.3.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Sin_Cos_Ratio	floating point type	Data type of results from a sine or cosine operation
Velocities	floating point type	Data type of velocity measurements
Wander_Angles	floating point type	Data type of wander angle measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Velocities * Sin_Cos_Ratio => Velocities
Sin_Cos	procedure	Returns the sine and cosine of a wander angle

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Nominal_East_Velocity	Velocities	In	Velocity which would be east if the wander angle was 0
Nominal_North_Velocity	Velocities	In	Velocity which would be north if the wander angle was 0
Current_Wander_Angle	Wander_Angles	In	Current wander azimuth angle

3.3.2.3.10.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Cos_of_Angle	Sin_Cos_Ratio	N/A	Cosine of current_wander_angle
Sin_of_Angle	Sin_Cos_Ratio	N/A	Sine of current_wander_angle

3.3.2.3.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_East_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles) return Velocities is

-- --------------------------
```

```
-- --declaration of variables-
-- ---------------------------

   Cos_of_Angle  : Sin_Cos_Ratio;
   Sin_of_Angle  : Sin_Cos_Ratio;

-------------------------------------
--begin function Compute_East_Velocity
-------------------------------------

begin

   Sin_Cos(Current_Wander_Angle, Sin_of_Angle, Cos_of_Angle);

   return ( Nominal_East_Velocity * Cos_of_Angle -
            Nominal_North_Velocity * Sin_of_Angle);

end Compute_East_Velocity;
```

3.3.2.3.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.1.8 LIMITATIONS

None.

3.3.2.3.10.2 COMPUTE_NORTH_VELOCITY UNIT DESIGN (CATALOG #P236-0)

This function calculates the North velocity component of a missile given the nominal north and east velocities of the missile.

The computations are performed as follows:

```
    VelN := VelNE * Sin(WA) + VelNN * Cos(WA)

    where VelNE = nominal east velocity
          VelNN = nominal north velocity
          WA    = wander angle
```

3.3.2.3.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R186.

3.3.2.3.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Sin_Cos_Ratio	floating point type	Data type defining results of a sine or cosine operation
Velocities	floating point type	Data type defining velocity measurements
Wander_Angle	floating point type	Data type defining wander angle measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Velocities * Sin_Cos_Ratio => Velocities
Sin_Cos	procedure	Procedure calculating sine and cosine values of a wander angle

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Nominal_East_Velocity	Velocities	In	Velocity in the direction which would be East if the wander angle was 0
Nominal_North_Velocity	Velocities	In	Velocity in the direction which would be North if the wander angle was 0
Current_Wander_Angle	Wander_Angles	In	Value of the current wander angle

3.3.2.3.10.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Cos_of_Angle	Sin_Cos_Ratio	N/A	Cosine of current_wander_angle
Sin_of_Angle	Sin_Cos_Ratio	N/A	Sine of current_wander_angle

3.3.2.3.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_North_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles) return Velocities is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Cos_of_Angle   : Sin_Cos_Ratio;
   Sin_of_Angle   : Sin_Cos_Ratio;

---------------------------------------
--begin function Compute_North_Velocity
---------------------------------------

begin

   Sin_Cos(Current_Wander_Angle, Sin_of_Angle, Cos_of_Angle);

   return ( Nominal_East_Velocity * Sin_of_Angle +
            Nominal_North_Velocity * Cos_of_Angle);

end Compute_North_Velocity;
```

3.3.2.3.10.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.2.8 LIMITATIONS

None.

3.3.2.3.10.3 COMPUTE_EARTH_RELATIVE_HORIZONTAL_VELOCITIES UNIT DESIGN (CATALOG #P237-0)

This procedure computes the north and east velocity given the nominal east and north velocities and the wander angle.

The computations are performed as follows:

```
VelE := VelNE * Cos(WA) - VelNN * Sin(WA)
VelN := VelNE * Sin(WA) + VelNN * Cos(WA)

where VelNE = nominal east velocity
      VelNN = nominal north velocity
      WA    = wander angle
```

3.3.2.3.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R001.

3.3.2.3.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Sin_Cos_Ratio	floating point type	Data type defining results of a sine or cosine operation
Velocities	floating point type	Data type defining velocity measurements
Wander_Angles	floating point type	Data type defining wander angle measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Velocities * Sin_Cos_Ratio => Velocities
Sin_Cos	procedure	Returns the sine and cosine of an input angle

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Nominal_East_Velocity	Velocities	In	Velocity in the direction that would be East if the wander angle was 0
Nominal_North_Velocity	Velocities	In	Velocity in the direct that would be North if the wander angle was 0
Current_Wander_Angle	Wander_Angles	In	Value of the current wander angle
East_Velocity	Velocities	Out	Current east velocity of the missile
North_Velocity	Velocities	Out	Current north velocity of the missile

3.3.2.3.10.3.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Cos_of_Angle	Sin_Cos_Ratio	N/A	Cosine of current_wander_angle
Sin_of_Angle	Sin_Cos_Ratio	N/A	Sine of current_wander_angle

3.3.2.3.10.3.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.3.6 PROCESSING

The following describes the processing performed by this part:

separate (Wander_Azimuth_Navigation_Parts)

```
procedure Compute_Earth_Relative_Horizontal_Velocities
            (Nominal_East_Velocity  : in  Velocities;
             Nominal_North_Velocity : in  Velocities;
             Current_Wander_Angle   : in  Wander_Angles;
             East_Velocity          : out Velocities;
             North_Velocity         : out Velocities) is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Cos_of_Angle : Sin_Cos_Ratio;
   Sin_of_Angle : Sin_Cos_Ratio;

------------------------------------------------------------------
--begin procedure Compute_Earth_Relative_Horizontal_Velocities
------------------------------------------------------------------

begin

   Sin_Cos(Current_Wander_Angle, Sin_of_Angle, Cos_of_Angle);

   East_Velocity := Nominal_East_Velocity * Cos_of_Angle -
                    Nominal_North_Velocity * Sin_of_Angle;
   North_Velocity := Nominal_East_Velocity * Sin_of_Angle +
                     Nominal_North_Velocity * Cos_of_Angle;

end Compute_Earth_Relative_Horizontal_Velocities;
```

3.3.2.3.10.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.3.8 LIMITATIONS

None.

3.3.2.3.10.4 COMPUTE_TOTAL_ANGULAR_VELOCITY UNIT DESIGN (CATALOG #P238-0)

This function computes the total angular velocity (which represents the ground speed) given the nominal north and east nominal velocities.

The computations are performed as follows:

```
    TAVel := Sqrt( RhoNN**2 + RhoNE**2)
```

where RhoNN = nominal north component of the current rotation rate of the missile's navigation frame with respect to the earth RhoNE = nominal east component of the current rotation rate of the missile's navigation frame with respect to the earth

3.3.2.3.10.4.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R004.

3.3.2.3.10.4.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.4.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	Data type used for angular velocity measurements
Angular_Velocity_Squared	floating point type	Data type of object resulting from the multiplication of two objects of type Angular_Velocity

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Angular_Velocities * Angular_Velocities => Angular_Velocity_Squared
Sqrt	function	Square root function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Rho_East	Angular_ Velocities	In	Nominal east component of the current rotation rate of the missile's navigation frame with repsect to the Earth
Rho_North	Angular_ Velocities	In	Nominal north component of the current rotation rate of the missile's navigation frame with repsect to the Earth

3.3.2.3.10.4.4 LOCAL DATA

None.

3.3.2.3.10.4.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.4.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Total_Angular_Velocity
            (Rho_East  : Angular_Velocities;
             Rho_North : Angular_Velocities) return Angular_Velocities is

begin

   return Sqrt(Rho_East * Rho_East + Rho_North * Rho_North);

end Compute_Total_Angular_Velocity;
```

3.3.2.3.10.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.4.8 LIMITATIONS

None.

3.3.2.3.10.5 COMPUTE_CORIOLIS_ACCELERATION UNIT DESIGN (CATALOG #P239-0)

This function computes the Coriolis acceleration given the velocity vector, Rho vector, and Omega vector.

The computations are performed as follows:

CorAccel := (2 * Omega Vector + Rho Vector) x Velocity Vector

3.3.2.3.10.5.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R007.

3.3.2.3.10.5.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.5.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Acceleration_Vector	private	Contains East, North, and vertical components of the Coriolis acceleration
Angular_Velocity_Vector	private	Contains East, North, and vertical components of the Earth's rotation rate
Velocity_Vector	private	Contains East, North, and vertical components of the missile's velocity

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Sparse_Right_X_Add	function	Adds two Angular_Velocity_Vector's assuming the x-component of the second vector equals 0
Sparse_Right_Z_Add	function	Adds two Angular_Velocity_Vector's assuming the z-component of the second vector equals 0
Cross_Product	function	Cross product function crossing an Angular_Velocity_Vector with a Velocity_Vector to obtain an Acceleration_Vector

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Velocity_In	Velocity_Vector	In	Contains the nominal East, North, and vertical components of the missile's current velocity
Rho_in	Angular_ Velocity_Vector	In	Contains the nominal East, North, and vertical components of the current earth-relative navigation frame rotation rate (vertical component assumed to equal 0 and is therefore ignored)
Omega_in	Angular_ Velocity_Vector	In	Contains the nominal East, North, and vertical components of the current Earth's rotation rate

3.3.2.3.10.5.4 LOCAL DATA

Data objects:.

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Temp_A_V_V	Angular_ Velocity_ Vector	N/A	Temporary angular velocity vector

3.3.2.3.10.5.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.5.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Coriolis_Acceleration
            (Velocity_In : Velocity_Vectors;
             Rho_In      : Angular_Velocity_Vectors;
             Omega_In    : Angular_Velocity_Vectors)
            return Acceleration_Vectors is

-- ----------------------------
-- --declaration of variables-
```

```
-- -------------------------

   Temp_A_V_V      : Angular_Velocity_Vectors;

-------------------------------------------
--begin function Compute_Coriolis_Acceleration
-------------------------------------------

begin

   Temp_A_V_V        := Omega_In + Omega_In;
   Temp_A_V_V        := Sparse_Right_Z_Add(Temp_A_V_V, Rho_In);

   return Cross_Product(Temp_A_V_V, Velocity_In);

end Compute_Coriolis_Acceleration;
```

3.3.2.3.10.5.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.5.8 LIMITATIONS

None.

3.3.2.3.10.6 COMPUTE_CURVATURES UNIT DESIGN (CATALOG #P241-0)

This generic function computes the inverse radius of curvature vector given three elements of the direction cosine matrix and the current altitude.

3.3.2.3.10.6.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R035.

3.3.2.3.10.6.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.6.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification of Wander_Azimuth_Navigation_Parts:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Indices	discrete type	Used to dimension Distance_Vectors
Direction_Cosine_Matrix_Elements	floating point type	Used to define elements of a direction cosine matrix
Distances	floating point type	Data type defining distance measurements
Inverse_Distances	floating point type	Data type of one over distance measurements
Real	floating point type	Data type used to define Earth_Flattening_Coefficient
Inverse_Distance_Vectors	array	Array of "Inverse_Distances" dimensioned by "Indices"

Data objects:

The following table summarizes the generic formal objects required by this part:

Name	Type	Description
Earth_Flattening_Coefficient	Real	Coefficient of earth flattening
One_Over_Earth_Radius	Inverse_Distances	Value of 1/Earth radius
NE	Indices	Indices'FIRST
NN	Indices	Indices'SUCC(NE)
V	Indices	Indices'LAST
Two_Flat	Real	2.0 * Earth_Flattening_Coefficient

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Distances * Inverse_Distances => Real
"*"	function	Multiplication operator defining the operation: Real * Direction_Cosine_Matrix_Elements => Real
"*"	function	Division operator defining the operation: Inverse_Distances * Real => Inverse_Distances

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_P_V	Direction_Cosine_Matrix_Elements	In	Sine of the current latitude of the missile
DC_P_NE	Direction_Cosine_Matrix_Elements	In	Product of the sine of the current wander angle and the cosine of the latitude
DC_P_NN	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the wander angle and the cosine of the latitude
Current_Altitude	Distances	In	Current altitude of the missile

3.3.2.3.10.6.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Denominator	Real	Intermediate calculation
Distance_Ratio	Real	Intermediate calculation
Partial_Denominator	Real	Intermediate calculation
Curvatures	Inverse_Distance_Vectors	Vector being calculated and returned
Two_Flat_x_DC_P_NN	Real	Intermediate calculation

3.3.2.3.10.6.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.6.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Curvatures
            (DC_P_V           : Direction_Cosine_Matrix_Elements;
             DC_P_NE          : Direction_Cosine_Matrix_Elements;
             DC_P_NN          : Direction_Cosine_Matrix_Elements;
             Current_Altitude : Distances)
            return Inverse_Distance_Vectors is

-- ----------------------------
-- --declaration of variables-
-- ----------------------------

   Denominator         : Real;
   Distance_Ratio      : Real;
```

```
   Partial_Denominator : Real;
   Curvatures          : Inverse_Distance_Vectors;
   Two_Flat_x_DC_P_NN  : Real;

------------------------
--beginning of function-
------------------------

begin

   Distance_Ratio      := Current_Altitude * One_Over_Earth_Radius;
   Partial_Denominator := 1.0 -
                          Distance_Ratio -
                          Earth_Flattening_Coefficient *
                            (DC_P_V * DC_P_V);

   Denominator     := Partial_Denominator +
                        Two_Flat * (DC_P_NE * DC_P_NE);
   Curvatures(NE) := One_Over_Earth_Radius * Denominator;

   Two_Flat_x_DC_P_NN := Two_Flat * DC_P_NN;
   Denominator        := Partial_Denominator +
                           Two_Flat_x_DC_P_NN * DC_P_NN;
   Curvatures(NN)     := One_Over_Earth_Radius * Denominator;

   Denominator    := Two_Flat_x_DC_P_NN * DC_P_NE;
   Curvatures(V) := One_Over_Earth_Radius * Denominator;

   return Curvatures;

end Compute_Curvatures;
```

3.3.2.3.10.6.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.6.8 LIMITATIONS

None.

3.3.2.3.10.7 TOTAL_PLATFORM_ROTATION_RATE (FUNCTION BODY) UNIT DESIGN (CATALOG #P242-0)

This function computes the rotation rate of the navigation coordinate system with respect to inertial space given the Rho and Omega vectors.

The computations performed are as follows:

TPR := Rho Vector + Omega Vector

3.3.2.3.10.7.1 REQUIREMENTS ALLOCATION

See main header for enclosing package.

3.3.2.3.10.7.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.7.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined when this part was specified.

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocity_Vectors	private	Array of angular velocity measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Sparse_Right_Z_ Add	function	Adds two angular velocity vectors assuming the third component of the right array equals 0

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Rho_Vector	Angular_Velocity_Vectors	In	Contains the nominal East, North, and vertical components of the rotation rate of the navigation coordinate system with respect to the earth (vertical component assumed to equal 0 and is therefore ignored)
Omega_Vector	Angular_Velocity_Vectors	In	Contains the nominal East, North, and vertical components of the earth's rotation rate

3.3.2.3.10.7.4 LOCAL DATA

None.

3.3.2.3.10.7.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.7.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Total_Platform_Rotation_Rate
           (Rho_Vector   : Angular_Velocity_Vectors;
            Omega_Vector : Angular_Velocity_Vectors)
           return Angular_Velocity_Vectors is
begin
   return Sparse_Right_Z_Add(Left  => Omega_Vector,
                             Right => Rho_Vector);
end Total_Platform_Rotation_Rate;
```

3.3.2.3.10.7.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.7.8 LIMITATIONS

None.

3.3.2.3.10.8 COMPUTE_EARTH_RELATIVE_NAVIGATION_ROTATION_RATE UNIT DESIGN (CATALOG #P244-0)

This function computes the rotation rate of the navigation coordinate system with respect to the Earth given the Velocity and Radius of Curvature vectors.

The computations are performed as follows:

```
RhoNE := - (VelNE * RCV)  - (VelNN * RCNN)
RhoNN :=   (VelNE * RCNE) + (VelNN * RCV )

where VelNx = nominal x-component of the missile's current velocity
      RCx   = nominal x-component of the radius of curvature
```

3.3.2.3.10.8.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement RO25.

3.3.2.3.10.8.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.8.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined in the package specification of Wander_Azimuth_Navigation_Parts:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Velocities	floating point type	Data type defining velocity measurements
Inverse_Distances	floating point type	Data type defining inverse distance measurements
Angular_Velocities	floating point type	Data type defining angular velocity measurements
Indices	discrete type	Data type used to dimension vector types
Angular_Velocity_Vectors	array	Array of angular velocities dimensioned by "Indices"
Velocity_Vectors	array	Array of velocities dimensioned by "Indices"
Inverse_Distance_Vectors	array	Array of inverse distances dimensioned by "Indices"

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
"/"	function	Division operator defining the operation: Velocities * Inverse_Distances => Angular_Velocities

FORMAL PARAMETERS:

The following table describes the formal parameters to the unit in this part:

Name	Type	Mode	Description
Missile_ Velocity	Velocity_Vectors	In	Contains nominal East and North components of the missile's current velocity
Curvatures	Inverse_ Distance_ Vectors	In	Contains nominal East, North, and vertical components of the inverse radius of curvature

3.3.2.3.10.8.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Rho	Angular_ Velocity_ Vectors	N/A	Vector being calculated and returned

3.3.2.3.10.8.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.8.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Earth_Relative_Navigation_Rotation_Rate
           (Missile_Velocity    : Velocity_Vectors;
            Curvatures          : Inverse_Distance_Vectors)
           return Angular_Velocity_Vectors is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------
```

```
   Rho      : Angular_Velocity_Vectors;

------------------------
--beginning of function-
------------------------

begin

   Rho(NE)  := - Missile_Velocity(NE) * Curvatures(V) -
                 Missile_Velocity(NN) * Curvatures(NN);
   Rho(NN)  := Missile_Velocity(NE) * Curvatures(NE) +
               Missile_Velocity(NN) * Curvatures(V);
   Rho(V)   := 0.0;

   return Rho;

end Compute_Earth_Relative_Navigation_Rotation_Rate;
```

3.3.2.3.10.8.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.8.8 LIMITATIONS

None.

3.3.2.3.10.9 COMPUTE_LATITUDE UNIT DESIGN (CATALOG #P245-0)

This function computes the current latitude given the sine of the latitude.

3.3.2.3.10.9.1 REQUIREMENTS ALLOCATION

See main header for enclosing package.

3.3.2.3.10.9.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.9.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined when this part was specified:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Positions	floating point type	Data type used to define longitude and latitude measurements
Sin_Cos_Ratio	floating point type	Data type used to define results from a sine or cosine operation

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Arcsin	function	Arcsine function

FORMAL PARAMETERS:

The following table describes the formal parameters for this part:

Name	Type	Mode	Description
Sin_Latitude	Sin_Cos_Ratio	In	Sine of the missile's current latitude

3.3.2.3.10.9.4 LOCAL DATA

None.

3.3.2.3.10.9.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.9.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Latitude (Sin_Latitude : Sin_Cos_Ratio)
                          return Earth_Positions is
begin
   return Arcsin(Sin_Latitude);
end Compute_Latitude;
```

3.3.2.3.10.9.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.9.8 LIMITATIONS

None.

3.3.2.3.10.10 COMPUTE_LATITUDE_USING_ARCTANGENT UNIT DESIGN (CATALOG #P246-0)

This function computes the current Latitude given some elements of the Direction Cosine matrix.

The computations are performed as follows:

Lat := Arctan(DCPV / SqRT(DCPNE**2 + DCPNN**2)

(see formal parameters section for explanation of abbreviations)

3.3.2.3.10.10.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R030

3.3.2.3.10.10.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.10.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Position	floating point type	Data type used to define latitude and longitude measurements
Tan_Ratio	floating point type	Data type used to define results of a tangent operation
Direction_Cosine_Matrix_Elements	floating point type	Data type used to define elements of a direction cosine matrix

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"/"	function	Division operator defining the operation: Direction_Cosine_Matrix_Elements / Direction_Cosine_Matrix_Elements => Tan_Ratio
Arctan	function	Arctangent function
Sqrt	function	Square root function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_P_V	Direction_Cosine_Matrix_Elements	In	Sine of the current latitude of the missile
DC_P_NE	Direction_Cosine_Matrix_Elements	In	Product of the sine of the wander angle and the cosine of the latitude
DC_P_NN	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the wander angle and the cosine of the latitude

3.3.2.3.10.10.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Denominator	Direction_Cosine_Matrix_Elements	N/A	Temporary variable used to hold results of intermediate calculations

3.3.2.3.10.10.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.10.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Latitude_Using_Arctangent
```

```
            (DC_P_V  : Direction_Cosine_Matrix_Elements;
             DC_P_NE : Direction_Cosine_Matrix_Elements;
             DC_P_NN : Direction_Cosine_Matrix_Elements)
            return Earth_Positions is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Denominator : Direction_Cosine_Matrix_Elements;

------------------------
--beginning of function-
------------------------

begin

   Denominator := Sqrt( DC_P_NE * DC_P_NE +
                        DC_P_NN * DC_P_NN );

   return Arctan(DC_P_V / Denominator);

end Compute_Latitude_Using_Arctangent;
```

3.3.2.3.10.10.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.10.8 LIMITATIONS

None.

3.3.2.3.10.11 COMPUTE_LONGITUDE UNIT DESIGN (CATALOG #P247-0)

This function computes the current longitude given some elements of the direction cosine matrix.

3.3.2.3.10.11.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R033

3.3.2.3.10.11.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.11.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Position	floating point type	Data type used to define latitude and longitude measurements
Tan_Ratio	floating point type	Data type used to define results of a tangent operation
Direction_Cosine_Matrix_Elements	floating point type	Data type used to define elements of a direction cosine matrix

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"/"	function	Division operator defining the operation: Direction_Cosine_Matrix_Elements / Direction_Cosine_Matrix_Elements => Tan_Ratio
Arctan	function	Arctangent function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_R_V	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the current latitude and the sine of the current longitude
DC_G_V	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the current latitude and the cosine of the current longitude

3.3.2.3.10.11.4 LOCAL DATA

None.

3.3.2.3.10.11.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.11.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Longitude (DC_R_V : Direction_Cosine_Matrix_Elements;
                            DC_G_V : Direction_Cosine_Matrix_Elements)
                           return Earth_Positions is

begin

   return Arctan(DC_R_V / DC_G_V);

end Compute_Longitude;
```

3.3.2.3.10.11.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.11.8 LIMITATIONS

None.

3.3.2.3.10.12 COMPUTE_WANDER_AZIMUTH_ANGLE UNIT DESIGN (CATALOG #P248-0)

This function computes the current wander azimuth angle given some elements of the Direction Cosine matrix.

The computations are performed as follows:

```
    WA := Arctan(DCPNE / DCPNN)
```

(see formal parameters section for explanation of abbreviations)

3.3.2.3.10.12.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R028

3.3.2.3.10.12.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.12.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Tan_Ratio	floating point type	Data type defining results of a tangent function
Direction_Cosine_Matrix_Elements	floating point type	Data type defining elements in a direction cosine matrix
Wander_Angles	floating point type	Data type defining wander angle measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"/"	function	Devision operator defining the operation: Direction_Cosine_Matrix_Elements / Direction_Cosine_Matrix_Elements => Tan_Ratio
Arctan	function	Arctangent function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_P_NE	Direction_Cosine_Matrix_Elements	In	Product of the sine of the wander angle and the cosine of the latitude
DC_P_NN	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the wander angle and the cosine of the latitude

3.3.2.3.10.12.4 LOCAL DATA

None.

3.3.2.3.10.12.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.12.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Wander_Azimuth_Angle
            (DC_P_NE : Direction_Cosine_Matrix_Elements;
             DC_P_NN : Direction_Cosine_Matrix_Elements)
            return Wander_Angles is

begin

   return Arctan(DC_P_NE / DC_P_NN);

end Compute_Wander_Azimuth_Angle;
```

3.3.2.3.10.12.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.12.8 LIMITATIONS

None.

3.3.2.3.10.13 COMPUTE_EAST_VELOCITY_WITH_SIN_COS_IN UNIT DESIGN (CATALOG #P1099-0)

This function computes the east velocity given the nominal east and north velocities and the wander angle.

The computations are performed as follows:

```
VelE := VelNE * Cos(WA) - VelNN * Sin(WA)

where VelNE = nominal east velocity
      VelNN = nominal north velocity
      WA    = wander angle
```

3.3.2.3.10.13.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.3.10.13.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.13.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Sin_Cos_Ratio	floating point type	Data type of results from a sine or cosine operation
Velocities	floating point type	Data type of velocity measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Sin_Cos	procedure	Returns the sine and cosine of a wander angle

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Nominal_East_Velocity	Velocities	In	Velocity which would be east if the wander angle was 0
Nominal_North_Velocity	Velocities	In	Velocity which would be north if the wander angle was 0
Sine_of_Wander_Angle	Sin_Cos_Ratio	In	Sine of the current wander azimuth angle
Cosine_of_Wander_Angle	Sin_Cos_Ratio	In	Cosine of the current wander azimuth angle

3.3.2.3.10.13.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Answer	Velocities	East velocity being calculated

3.3.2.3.10.13.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.13.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_East_Velocity_with_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_of_Wander_Angle : Sin_Cos_Ratio) return Velocities is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Answer : Velocities;

--------------------------------------
--begin function Compute_East_Velocity
--------------------------------------

begin

   Answer := Nominal_East_Velocity  * Cosine_of_Wander_Angle -
             Nominal_North_Velocity * Sine_of_Wander_Angle;

   return Answer;

end Compute_East_Velocity_with_Sin_Cos_In;
```

3.3.2.3.10.13.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.13.8 LIMITATIONS

None.

3.3.2.3.10.14 COMPUTE_NORTH_VELOCITY_WITH_SIN_COS_IN UNIT DESIGN (CATALOG #P1101-0)

This function calculates the North velocity component of a missile given the nominal north and east velocities of the missile.

The computations are performed as follows:

```
VelN := VelNE * Sin(WA) + VelNN * Cos(WA)

where VelNE = nominal east velocity
      VelNN = nominal north velocity
      WA    = wander angle
```

3.3.2.3.10.14.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.3.10.14.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.14.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Sin_Cos_Ratio	floating point type	Data type defining results of a sine or cosine operation
Velocities	floating point type	Data type defining velocity measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Velocities * Sin_Cos_Ratio => Velocities

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Nominal_East_Velocity	Velocities	In	Velocity in the direction which would be East if the wander angle was 0
Nominal_North_Velocity	Velocities	In	Velocity in the direction which would be North if the wander angle was 0
Sine_of_Wander_Angle	Sin_Cos_Ratio	In	Sine of the current wander azimuth angle
Cosine_of_Wander_Angle	Sin_Cos_Ratio	In	Cosine of the current wander azimuth angle

3.3.2.3.10.14.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Answer	Velocities	North velocity being calculated

3.3.2.3.10.14.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.14.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_North_Velocity_with_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_of_Wander_Angle : Sin_Cos_Ratio) return Velocities is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Answer : Velocities;

----------------------------------------
--begin function Compute_North_Velocity
```

```
---------------------------------------

begin

   Answer := Nominal_East_Velocity  * Sine_of_Wander_Angle +
             Nominal_North_Velocity * Cosine_of_Wander_Angle;

   return Answer;

end Compute_North_Velocity_with_Sin_Cos_In;
```

3.3.2.3.10.14.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.14.8 LIMITATIONS

None.

3.3.2.3.10.15 COMPUTE_EARTH_RELATIVE_HORIZONTAL_VELOCITIES_WITH_SIN_COS_IN UNIT DESIGN (CATALOG #P1107-0)

This procedure computes the north and east velocity given the nominal east and north velocities and the wander angle.

The computations are performed as follows:

```
    VelE := VelNE * Cos(WA) - VelNN * Sin(WA)
    VelN := VelNE * Sin(WA) + VelNN * Cos(WA)

    where VelNE = nominal east velocity
          VelNN = nominal north velocity
          WA    = wander angle
```

3.3.2.3.10.15.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.3.10.15.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.15.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Sin_Cos_Ratio	floating point type	Data type defining results of a sine or cosine operation
Velocities	floating point type	Data type defining velocity measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	Multiplication operator defining the operation: Velocities * Sin_Cos_Ratio => Velocities

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Nominal_East_Velocity	Velocities	In	Velocity in the direction that would be East if the wander angle was 0
Nominal_North_Velocity	Velocities	In	Velocity in the direct that would be North if the wander angle was 0
Current_Wander_Angle	Wander_Angles	In	Value of the current wander angle
Sine_of_Wander_Angle	Sin_Cos_Ratio	In	Sine of the current wander azimuth angle
Cosine_of_Wander_Angle	Sin_Cos_Ratio	In	Cosine of the current wander azimuth angle
East_Velocity	Velocities	Out	Current east velocity of the missile
North_Velocity	Velocities	Out	Current north velocity of the missile

3.3.2.3.10.15.4 LOCAL DATA

None.

3.3.2.3.10.15.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.15.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
procedure Compute_Earth_Relative_Horizontal_Velocities_with_Sin_Cos_In
             (Nominal_East_Velocity  : in     Velocities;
              Nominal_North_Velocity : in     Velocities;
              Sine_of_Wander_Angle   : in     Sin_Cos_Ratio;
              Cosine_of_Wander_Angle : in     Sin_Cos_Ratio;
              East_Velocity          :    out Velocities;
              North_Velocity         :    out Velocities) is

begin

   East_Velocity := Nominal_East_Velocity * Cosine_of_Wander_Angle -
                    Nominal_North_Velocity * Sine_of_Wander_Angle;
   North_Velocity := Nominal_East_Velocity * Sine_Of_Wander_Angle +
                     Nominal_North_Velocity * Cosine_of_Wander_Angle;

end Compute_Earth_Relative_Horizontal_Velocities_with_Sin_Cos_In;
```

3.3.2.3.10.15.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.15.8 LIMITATIONS

None.

3.3.2.3.10.16 COMPUTE_LATITUDE_USING_TWO_VALUE_ARCTANGENT UNIT DESIGN (CATALOG #P1104-0)

This function computes the current Latitude given some elements of the Direction Cosine matrix.

The computations are performed as follows:

```
    Lat := Arctan(DCPV / SqRT(DCPNE**2 + DCPNN**2)
```

(see formal parameters section for explanation of abbreviations)

3.3.2.3.10.16.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.3.10.16.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.16.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Position	floating point type	Data type used to define latitude and longitude measurements
Direction_Cosine_Matrix_Elements	floating point type	Data type used to define elements of a direction cosine matrix

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Arctan2	function	4-quadrant arctangent function
Sqrt	function	Square root function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_P_V	Direction_Cosine_Matrix_Elements	In	Sine of the current latitude of the missile
DC_P_NE	Direction_Cosine_Matrix_Elements	In	Product of the sine of the wander angle and the cosine of the latitude
DC_P_NN	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the wander angle and the cosine of the latitude

3.3.2.3.10.16.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Answer	Earth_Positions	Latitude being calculated
Denominator	Direction_Cosine_Matrix_Elements	Temporary variable used to hold results of intermediate calculations

3.3.2.3.10.16.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.16.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Latitude_Using_Two_Value_Arctangent
           (DC_P_V  : Direction_Cosine_Matrix_Elements;
            DC_P_NE : Direction_Cosine_Matrix_Elements;
            DC_P_NN : Direction_Cosine_Matrix_Elements)
           return Earth_Positions is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Answer      : Earth_Positions;
   Denominator : Direction_Cosine_Matrix_Elements;

------------------------
--beginning of function-
------------------------

begin

   Denominator := Sqrt( DC_P_NE * DC_P_NE +
                        DC_P_NN * DC_P_NN );

   Answer := Arctan2 (Y => DC_P_V,
                      X => Denominator);

   return Answer;

end Compute_Latitude_Using_Two_Value_Arctangent;
```

3.3.2.3.10.16.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.16.8 LIMITATIONS

None.

3.3.2.3.10.17 COMPUTE_LONGITUDE_USING_TWO_VALUE_ARCTANGENT UNIT DESIGN (CATALOG #P1106-0)

This function computes the current longitude given some elements of the direction cosine matrix.

3.3.2.3.10.17.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.3.10.17.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.17.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Position	floating point type	Data type used to define latitude and longitude measurements
Direction_Cosine_Matrix_Elements	floating point type	Data type used to define elements of a direction cosine matrix

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Arctan2	function	4-quadrant arctangent function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_R_V	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the current latitude and the sine of the current longitude
DC_G_V	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the current latitude and the cosine of the current longitude

3.3.2.3.10.17.4 LOCAL DATA

None.

3.3.2.3.10.17.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.17.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Longitude_using_Two_Value_Arctangent
            (DC_R_V : Direction_Cosine_Matrix_Elements;
             DC_G_V : Direction_Cosine_Matrix_Elements)
            return Earth_Positions is

-- ---------------------
-- --declaration section
-- ---------------------

   Answer : Earth_Positions;

-----------------
--begin function
----------------

begin

   return Arctan2 (Y => DC_R_V,
                   X => DC_G_V);

end Compute_Longitude_using_Two_Value_Arctangent;
```

3.3.2.3.10.17.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.17.8 LIMITATIONS

None.

3.3.2.3.10.18 COMPUTE_WANDER_AZIMUTH_ANGLE_USING_TWO_VALUE_ARCTANGENT UNIT DESIGN (CATALOG #P1109-0)

This function computes the current wander azimuth angle given some elements of the Direction Cosine matrix.

The computations are performed as follows:

WA := Arctan(DCPNE / DCPNN)

(see formal parameters section for explanation of abbreviations)

3.3.2.3.10.18.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R028

3.3.2.3.10.18.2 LOCAL ENTITIES DESIGN

None.

3.3.2.3.10.18.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following generic parameters were previously defined for this part's specification in the Wander_Azimuth_Navigation_Parts package specification:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Direction_Cosine_Matrix_Elements	floating point type	Data type defining elements in a direction cosine matrix
Wander_Angles	floating point type	Data type defining wander angle measurements

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Arctan2	function	4-quadrant Arctangent function

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_P_NE	Direction_Cosine_Matrix_Elements	In	Product of the sine of the wander angle and the cosine of the latitude
DC_P_NN	Direction_Cosine_Matrix_Elements	In	Product of the cosine of the wander angle and the cosine of the latitude

3.3.2.3.10.18.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Answer	Wander_Angles	Wander angle being calculated

3.3.2.3.10.18.5 PROCESS CONTROL

Not applicable.

3.3.2.3.10.18.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Wander_Azimuth_Angle_using_Two_Value_Arctangent
            (DC_P_NE : Direction_Cosine_Matrix_Elements;
             DC_P_NN : Direction_Cosine_Matrix_Elements)
            return Wander_Angles is

-- ---------------------
-- --declaration section
-- ---------------------
```

```
   Answer : Wander_Angles;

----------------
--begin function
----------------

begin

   Answer := Arctan2 (Y => DC_P_NE,
                      X => DC_P_NN);

   return Answer;

end Compute_Wander_Azimuth_Angle_using_Two_Value_Arctangent;
```

3.3.2.3.10.18.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.3.10.18.8 LIMITATIONS

None.

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```
package body Wander_Azimuth_Navigation_Parts is

   function Compute_East_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles)
            return Velocities is separate;

   function Compute_East_Velocity_With_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_Of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_Of_Wander_Angle : Sin_Cos_Ratio)
            return Velocities is separate;

   function Compute_North_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles)
            return Velocities is separate;

   function Compute_North_Velocity_With_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_Of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_Of_Wander_Angle : Sin_Cos_Ratio)
            return Velocities is separate;

   procedure Compute_Earth_Relative_Horizontal_Velocities
             (Nominal_East_Velocity  : in  Velocities;
              Nominal_North_Velocity : in  Velocities;
              Current_Wander_Angle   : in  Wander_Angles;
              East_Velocity          : out Velocities;
              North_Velocity         : out Velocities)
             is separate;

   procedure Compute_Earth_Relative_Horizontal_Velocities_With_Sin_Cos_In
             (Nominal_East_Velocity  : in     Velocities;
              Nominal_North_Velocity : in     Velocities;
              Sine_Of_Wander_Angle   : in     Sin_Cos_Ratio;
              Cosine_Of_Wander_Angle : in     Sin_Cos_Ratio;
              East_Velocity          :    out Velocities;
              North_Velocity         :    out Velocities)
             is separate;

   function Compute_Total_Angular_Velocity
            (Rho_East  : Angular_Velocities;
             Rho_North : Angular_Velocities)
            return Angular_Velocities is separate;

   function Compute_Coriolis_Acceleration
            (Velocity_In : Velocity_Vectors;
             Rho_In      : Angular_Velocity_Vectors;
             Omega_In    : Angular_Velocity_Vectors)
            return Acceleration_Vectors is separate;

   package body Coriolis_Acceleration_From_Total_Rates is separate;
```

```
   function Compute_Curvatures
               (Dc_P_V           : Direction_Cosine_Matrix_Elements;
                Dc_P_Ne          : Direction_Cosine_Matrix_Elements;
                Dc_P_Nn          : Direction_Cosine_Matrix_Elements;
                Current_Altitude : Distances)
               return Inverse_Distance_Vectors is separate;

   function Total_Platform_Rotation_Rate
               (Rho_Vector   : Angular_Velocity_Vectors;
                Omega_Vector : Angular_Velocity_Vectors)
               return Angular_Velocity_Vectors is separate;

   package body Earth_Rotation_Rate is separate;

   function Compute_Earth_Relative_Navigation_Rotation_Rate
               (Missile_Velocity    : Velocity_Vectors;
                Curvatures          : Inverse_Distance_Vectors)
               return Angular_Velocity_Vectors is separate;

   function Compute_Latitude (Sin_Latitude : Sin_Cos_Ratio)
                             return Earth_Positions is separate;

   function Compute_Latitude_Using_Arctangent
               (Dc_P_V  : Direction_Cosine_Matrix_Elements;
                Dc_P_Ne : Direction_Cosine_Matrix_Elements;
                Dc_P_Nn : Direction_Cosine_Matrix_Elements)
               return Earth_Positions is separate;

   function Compute_Latitude_Using_Two_Value_Arctangent
               (Dc_P_V  : Direction_Cosine_Matrix_Elements;
                Dc_P_Ne : Direction_Cosine_Matrix_Elements;
                Dc_P_Nn : Direction_Cosine_Matrix_Elements)
               return Earth_Positions is separate;

   function Compute_Longitude
               (Dc_R_V : Direction_Cosine_Matrix_Elements;
                Dc_G_V : Direction_Cosine_Matrix_Elements)
               return Earth_Positions is separate;

   function Compute_Longitude_Using_Two_Value_Arctangent
               (Dc_R_V : Direction_Cosine_Matrix_Elements;
                Dc_G_V : Direction_Cosine_Matrix_Elements)
               return Earth_Positions is separate;

   function Compute_Wander_Azimuth_Angle
               (Dc_P_Ne : Direction_Cosine_Matrix_Elements;
                Dc_P_Nn : Direction_Cosine_Matrix_Elements)
               return Wander_Angles is separate;

   function Compute_Wander_Azimuth_Angle_Using_Two_Value_Arctangent
               (Dc_P_Ne : Direction_Cosine_Matrix_Elements;
                Dc_P_Nn : Direction_Cosine_Matrix_Elements)
               return Wander_Angles is separate;

end Wander_Azimuth_Navigation_Parts;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_East_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles) return Velocities is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Cos_Of_Angle  : Sin_Cos_Ratio;
   Sin_Of_Angle  : Sin_Cos_Ratio;

---------------------------------------
--begin function Compute_East_Velocity
---------------------------------------

begin

   Sin_Cos(Current_Wander_Angle, Sin_Of_Angle, Cos_Of_Angle);

   return ( Nominal_East_Velocity * Cos_Of_Angle -
            Nominal_North_Velocity * Sin_Of_Angle);

end Compute_East_Velocity;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_North_Velocity
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Current_Wander_Angle   : Wander_Angles) return Velocities is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Cos_Of_Angle   : Sin_Cos_Ratio;
   Sin_Of_Angle   : Sin_Cos_Ratio;

-------------- ---------------------------
--begin function Compute_North_Velocity
---------------------------------------

begin

   Sin_Cos(Current_Wander_Angle, Sin_Of_Angle, Cos_Of_Angle);

   return ( Nominal_East_Velocity * Sin_Of_Angle +
            Nominal_North_Velocity * Cos_Of_Angle);

end Compute_North_Velocity;
```

```
separate (Wander_Azimuth_Navigation_Parts)
procedure Compute_Earth_Relative_Horizontal_Velocities
            (Nominal_East_Velocity  : in  Velocities;
             Nominal_North_Velocity : in  Velocities;
             Current_Wander_Angle   : in  Wander_Angles;
             East_Velocity          : out Velocities;
             North_Velocity         : out Velocities) is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Cos_Of_Angle : Sin_Cos_Ratio;
   Sin_Of_Angle : Sin_Cos_Ratio;

------------------------------------------------------------------
--begin procedure Compute_Earth_Relative_Horizontal_Velocities
------------------------------------------------------------------

begin

   Sin_Cos(Current_Wander_Angle, Sin_Of_Angle, Cos_Of_Angle);

   East_Velocity := Nominal_East_Velocity * Cos_Of_Angle -
                    Nominal_North_Velocity * Sin_Of_Angle;
   North_Velocity := Nominal_East_Velocity * Sin_Of_Angle +
                     Nominal_North_Velocity * Cos_Of_Angle;

end Compute_Earth_Relative_Horizontal_Velocities;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Total_Angular_Velocity
            (Rho_East  : Angular_Velocities;
             Rho_North : Angular_Velocities) return Angular_Velocities is

begin

   return Sqrt(Rho_East * Rho_East + Rho_North * Rho_North);

end Compute_Total_Angular_Velocity;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Coriolis_Acceleration
            (Velocity_In : Velocity_Vectors;
             Rho_In      : Angular_Velocity_Vectors;
             Omega_In    : Angular_Velocity_Vectors)
            return Acceleration_Vectors is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Temp_A_V_V      : Angular_Velocity_Vectors;

-----------------------------------------------
--begin function Compute_Coriolis_Acceleration
-----------------------------------------------

begin

   Temp_A_V_V         := Omega_In + Omega_In;
   Temp_A_V_V         := Sparse_Right_Z_Add(Temp_A_V_V, Rho_In);

   return Cross_Product(Temp_A_V_V, Velocity_In);

end Compute_Coriolis_Acceleration;
```

```
separate (Wander_Azimuth_Navigation_Parts)
package body Coriolis_Acceleration_From_Total_Rates is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   E               : constant Indice  := Indices'FIRST;
   N               : constant Indices := Indices'SUCC(E);
   U               : constant Indices := Indices'LAST;

pragma PAGE;
-- ------------
-- --unit body-
-- ------------

   function Compute (Velocity_In : Velocity_Vectors;
                     Omega       : Angular_Velocity_Vectors;
                     Total_Rates : Angular_Velocity_Vectors)
                    return Acceleration_Vectors is

--    ---------------------------
--    --declaration of variables-
--    ---------------------------

      Temp_A_V_V      : Angular_Velocity_Vectors;

-- -------------------------
-- --begin function Compute
-- -------------------------

   begin

      Temp_A_V_V(E) := Omega(E) + Total_Rates(E);
      Temp_A_V_V(N) := Omega(N) + Total_Rates(N);
      Temp_A_V_V(U) := Omega(U) + Omega(U);

      return Cross_Product(Temp_A_V_V, Velocity_In);

   end Compute;

end Coriolis_Acceleration_From_Total_Rates;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Curvatures
            (Dc_P_V           : Direction_Cosine_Matrix_Elements;
             Dc_P_Ne          : Direction_Cosine_Matrix_Elements;
             Dc_P_Nn          : Direction_Cosine_Matrix_Elements;
             Current_Altitude : Distances)
            return Inverse_Distance_Vectors is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Denominator         : Real,
   Distance_Ratio      : Real;
   Partial_Denominator : Real;
   Curvatures          : Inverse_Distance_Vectors;
   Two_Flat_X_Dc_P_Nn  : Real;

-------------------------
--beginning of function-
-------------------------

begin

   Distance_Ratio      := Current_Altitude * One_Over_Earth_Radius;
   Partial_Denominator := 1.0 -
                          Distance_Ratio -
                          Earth_Flattening_Coefficient *
                            (Dc_P_V * Dc_P_V);

   Denominator    := Partial_Denominator +
                         Two_Flat * (Dc_P_Ne * Dc_P_Ne);
   Curvatures(Ne) := One_Over_Earth_Radius * Denominator;

   Two_Flat_X_Dc_P_Nn := Two_Flat * Dc_P_Nn;
   Denominator        := Partial_Denominator +
                           Two_Flat_X_Dc_P_Nn * Dc_P_Nn;
   Curvatures(Nn)     := One_Over_Earth_Radius * Denominator;

   Denominator   := Two_Flat_X_Dc_P_Nn * Dc_P_Ne;
   Curvatures(V) := One_Over_Earth_Radius * Denominator;

   return Curvatures;

end Compute_Curvatures;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Total_Platform_Rotation_Rate
            (Rho_Vector   : Angular_Velocity_Vectors;
             Omega_Vector : Angular_Velocity_Vectors)
            return Angular_Velocity_Vectors is
begin
   return Sparse_Right_Z_Add(Left  => Omega_Vector,
                             Right => Rho_Vector);
end Total_Platform_Rotation_Rate;
```

```
separate (Wander_Azimuth_Navigation_Parts)
package body Earth_Rotation_Rate is

-- --------------------
-- --local declarations
-- --------------------

   Ne             : constant Indices := Indices'FIRST;
   Nn             : constant Indices := Indices'SUCC(Ne);
   V              : constant Indices := Indices'LAST;

pragma PAGE;
-- ------------
-- --unit body-
-- ------------

   function Compute (Dc_P_V  : Direction_Cosine_Matrix_Elements;
                     Dc_P_Ne : Direction_Cosine_Matrix_Elements;
                     Dc_P_Nn : Direction_Cosine_Matrix_Elements)
                    return Angular_Velocity_Vectors is

--    ----------------------------
--    --declaration of variables-
--    ----------------------------

      Rotation_Rate : Angular_Velocity_Vectors;

-- ------------------------
-- --beginning of function-
-- ------------------------

   begin

      Rotation_Rate(Ne) := Dc_P_Ne * Earth_Rate;
      Rotation_Rate(Nn) := Dc_P_Nn * Earth_Rate;
      Rotation_Rate(V)  := Dc_P_V * Earth_Rate;

      return Rotation_Rate;

   end Compute;

end Earth_Rotation_Rate;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Earth_Relative_Navigation_Rotation_Rate
           (Missile_Velocity    : Velocity_Vectors;
            Curvatures          : Inverse_Distance_Vectors)
           return Angular_Velocity_Vectors is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Rho      : Angular_Velocity_Vectors;

------------------------
--beginning of function-
------------------------

begin

   Rho(Ne)  := - Missile_Velocity(Ne) * Curvatures(V) -
                 Missile_Velocity(Nn) * Curvatures(Nn);
   Rho(Nn)  := Missile_Velocity(Ne) * Curvatures(Ne) +
               Missile_Velocity(Nn) * Curvatures(V);
   Rho(V)   := 0.0;

   return Rho;

end Compute_Earth_Relative_Navigation_Rotation_Rate;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Latitude (Sin_Latitude : Sin_Cos_Ratio)
                          return Earth_Positions is
begin
   return Arcsin(Sin_Latitude);
end Compute_Latitude;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Latitude_Using_Arctangent
            (Dc_P_V  : Direction_Cosine_Matrix_Elements;
             Dc_P_Ne : Direction_Cosine_Matrix_Elements;
             Dc_P_Nn : Direction_Cosine_Matrix_Elements)
            return Earth_Positions is

-- ----------------------------
-- --declaration of variables-
-- ----------------------------

   Denominator : Direction_Cosine_Matrix_Elements;

-------------------------
--beginning of function-
-------------------------

begin

   Denominator := Sqrt( Dc_P_Ne * Dc_P_Ne +
                        Dc_P_Nn * Dc_P_Nn );

   return Arctan(Dc_P_V / Denominator);

end Compute_Latitude_Using_Arctangent;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Longitude (Dc_R_V : Direction_Cosine_Matrix_Elements;
                            Dc_G_V : Direction_Cosine_Matrix_Elements)
                           return Earth_Positions is

begin

   return Arctan(Dc_R_V / Dc_G_V);

end Compute_Longitude;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Wander_Azimuth_Angle
            (Dc_P_Ne : Direction_Cosine_Matrix_Elements;
             Dc_P_Nn : Direction_Cosine_Matrix_Elements)
            return Wander_Angles is

begin

   return Arctan(Dc_P_Ne / Dc_P_Nn);

end Compute_Wander_Azimuth_Angle;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_East_Velocity_With_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_Of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_Of_Wander_Angle : Sin_Cos_Ratio) return Velocities is

-- ----------------------------
-- --declaration of variables-
-- ----------------------------

   Answer : Velocities;

---------------------------------------
--begin function Compute_East_Velocity
---------------------------------------

begin

   Answer := Nominal_East_Velocity  * Cosine_Of_Wander_Angle -
             Nominal_North_Velocity * Sine_Of_Wander_Angle;

   return Answer;

end Compute_East_Velocity_With_Sin_Cos_In;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_North_Velocity_With_Sin_Cos_In
            (Nominal_East_Velocity  : Velocities;
             Nominal_North_Velocity : Velocities;
             Sine_Of_Wander_Angle   : Sin_Cos_Ratio;
             Cosine_Of_Wander_Angle : Sin_Cos_Ratio) return Velocities is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Answer : Velocities;

---------------------------------------
--begin function Compute_North_Velocity
---------------------------------------

begin

   Answer := Nominal_East_Velocity  * Sine_Of_Wander_Angle +
             Nominal_North_Velocity * Cosine_Of_Wander_Angle;

   return Answer;

end Compute_North_Velocity_With_Sin_Cos_In;
```

```
separate (Wander_Azimuth_Navigation_Parts)
procedure Compute_Earth_Relative_Horizontal_Velocities_With_Sin_Cos_In
            (Nominal_East_Velocity  : in     Velocities;
             Nominal_North_Velocity : in     Velocities;
             Sine_Of_Wander_Angle   : in     Sin_Cos_Ratio;
             Cosine_Of_Wander_Angle : in     Sin_Cos_Ratio;
             East_Velocity          :    out Velocities;
             North_Velocity         :    out Velocities) is

begin

   East_Velocity := Nominal_East_Velocity * Cosine_Of_Wander_Angle -
                    Nominal_North_Velocity * Sine_Of_Wander_Angle;
   North_Velocity := Nominal_East_Velocity * Sine_Of_Wander_Angle +
                     Nominal_North_Velocity * Cosine_Of_Wander_Angle;

end Compute_Earth_Relative_Horizontal_Velocities_With_Sin_Cos_In;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Latitude_Using_Two_Value_Arctangent
            (Dc_P_V  : Direction_Cosine_Matrix_Elements;
             Dc_P_Ne : Direction_Cosine_Matrix_Elements;
             Dc_P_Nn : Direction_Cosine_Matrix_Elements)
            return Earth_Positions is

-- ---------------------------
-- --declaration of variables-
-- ---------------------------

   Answer      : Earth_Positions;
   Denominator : Direction_Cosine_Matrix_Elements;

------------------------
--beginning of function-
------------------------

begin

   Denominator := Sqrt( Dc_P_Ne * Dc_P_Ne +
                        Dc_P_Nn * Dc_P_Nn );

   Answer := Arctan2 (Y => Dc_P_V,
                      X => Denominator);

   return Answer;

end Compute_Latitude_Using_Two_Value_Arctangent;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Longitude_Using_Two_Value_Arctangent
            (Dc_R_V : Direction_Cosine_Matrix_Elements;
             Dc_G_V : Direction_Cosine_Matrix_Elements)
            return Earth_Positions is

-- ---------------------
-- --declaration section
-- ---------------------

   Answer : Earth_Positions;

-----------------
--begin function
-----------------

begin

   return Arctan2 (Y => Dc_R_V,
                   X => Dc_G_V);

end Compute_Longitude_Using_Two_Value_Arctangent;
```

```
separate (Wander_Azimuth_Navigation_Parts)
function Compute_Wander_Azimuth_Angle_Using_Two_Value_Arctangent
            (Dc_P_Ne : Direction_Cosine_Matrix_Elements;
             Dc_P_Nn : Direction_Cosine_Matrix_Elements)
            return Wander_Angles is

-- ---------------------
-- --declaration section
-- ---------------------

   Answer : Wander_Angles;

----------------
--begin function
----------------

begin

   Answer := Arctan2 (Y => Dc_P_Ne,
                      X => Dc_P_Nn);

   return Answer;

end Compute_Wander_Azimuth_Angle_Using_Two_Value_Arctangent;
```

3.3.2.4 DIRECTION_COSINE_MATRIX_OPERATIONS (PACKAGE BODY) TLCSC P644 (CATALOG #P286-0)

This part is the body of an Ada package that contains units for all CAMP parts that initialize or update a direction cosine matrix (DCM). A direction cosine matrix is a 3x3 matrix whose elements are cosines of the angles between two coordinate frames - xyz and XYZ. The direction cosines are used to transform data values represented in one coordinate frame to another coordinate frame.

This part consists of two packages. The first package contains all parts which operate on a "general" direction cosine matrix. A "general" DCM is a DCM that does not assume particular coordinate frames, i.e. the Navigation to Earth. However, these parts do assume a particular coordinate frame axes relationship (for an example, see the preceding paragraph). The user should refer to the documentation for each part to determine if the unit can be used for a particular application.

The second package contains all operations that operate on a CNE matrix. The CNE matrix is a direction cosine matrix that is used to transform objects from the navigation frame to the earth frame. The navigation frame assumes "East, North, and Up" (for XYZ), and the earth frame assumes "Greenwich, Right, and Polar" (for xyz) for the axes definitions. These coordinate assumptions are reflected in the generic objects of the package. This package exports a CNE matrix type representing a CNE matrix derived from these coordinate assumptions.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.1 REQUIREMENTS ALLOCATION

The following chart summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
DCM_General_Operations	R34
CNE_Operations	R32

3.3.2.4.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.3 INPUT/OUTPUT

None.

3.3.2.4.4 LOCAL DATA

None.

3.3.2.4.5 PROCESS CONTROL

Not applicable.

3.3.2.4.6 PROCESSING

The following describes the processing performed by this part:

```
package body Direction_Cosine_Matrix_Operations is
   package body DCM_General_Operations is separate;
   package body CNE_Operations is separate;
end Direction_Cosine_Matrix_Operations;
```

3.3.2.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.8 LIMITATIONS

None.

3.3.2.4.9 LLCSC DESIGN

3.3.2.4.9.1 DCM_GENERAL_OPERATIONS PACKAGE DESIGN (CATALOG #P287-0)

This package contains procedures and functions which operate on a "general" direction cosine matrix. A specific coordinate frame axis ordering has been assumed for the parts; therefore, refer to the documentation for each part before using it.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.9.1.1 REQUIREMENTS ALLOCATION

The following table summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
DCM_Initialized_From_Reference	N/A
Perform_Trapezoidal_Integration_of_DCM	R34
Perform_Rectangular_Integration_of_DCM	N/A
Reorthonormalize_DCM	N/A
Frame_Misalignment	N/A
Aligned_DCM_Matrix	N/A
Compute_First_Row_From_Orthonormal	N/A
DCM_From_Quaternion	N/A

3.3.2.4.9.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.3 INPUT/OUTPUT

None.

3.3.2.4.9.1.4 LOCAL DATA

None.

3.3.2.4.9.1.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations)
package body DCM_General_Operations is
```

```
   function DCM_Initialized_From_Reference
               (Ref_DCM_2_1    : Sin_Cos_Ratio;
                Ref_DCM_2_2    : Sin_Cos_Ratio;
                Ref_DCM_3_1    : Sin_Cos_Ratio;
                Ref_DCM_3_2    : Sin_Cos_Ratio;
                Sign_Of_2_3    : INTEGER;
                Sign_Of_3_3    : INTEGER)
               return Direction_Cosine_Matrix is separate;

   package body DCM_Trapezoidal_Integration is separate;

   procedure Perform_Rectangular_Integration_of_DCM
               (DC_Matrix  : in out Direction_Cosine_Matrix;
                X_Rho      : in     Angular_Velocities;
                Y_Rho      : in     Angular_Velocities;
                Delta_Time : in     Time_Intervals) is separate;

   procedure Reorthonormalize_DCM
               (DCM_Matrix  : in out Direction_Cosine_Matrix) is separate;

   function Frame_Misalignment
               (DCM_Matrix     : Direction_Cosine_Matrix;
                Ref_DC_Matrix  : Direction_Cosine_Matrix)
               return Rotation_Angle_Vec is separate;

   function Aligned_DCM_Matrix
               (DCM_Matrix      : Direction_Cosine_Matrix;
                Rotation_Angle  : Rotation_Angle_Vec)
               return Direction_Cosine_Matrix is separate;

   procedure Compute_First_Row_From_Orthonormal
               (DCM_Matrix      : in out Direction_Cosine_Matrix) is separate;

   function DCM_From_Quaternion
               (Quaternion : Quaternion_Vectors)
               return Direction_Cosine_Matrix is separate;

end DCM_General_Operations;
```

3.3.2.4.9.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.8 LIMITATIONS

None.

3.3.2.4.9.1.9 LLCSC DESIGN

3.3.2.4.9.1.9.1 DCM_TRAPEZOIDAL_INTEGRATION PACKAGE DESIGN (CATALOG #P289-0)

This package contains a procedure that integrates a direction cosine matrix using trapezoidal integration. NOTE: Only rows 2 and 3 are integrated by this part. Row 1 is usually updated from rows 2 and 3 - the user must update row 1 manually.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.9.1.9.1.1 REQUIREMENTS ALLOCATION

The following table summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
Perform_Trapezoidal_Integration_of_DCM	R34

3.3.2.4.9.1.9.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	This type translates into the type of the angular velocity used to integrate the direction cosine matrix.
Time_Intervals	floating point type	This type translates into the type of the time parameter used to integrate the direction cosine matrix.
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Initial_X_Rho	Angular_Velocities	0 or user-defined	Object used to set the initial angular velocity X_Rho to either 0 (by default) or to a user-specified value. Note that this value is set at compile time. To set the value at run time, use the reinitialize procedure.
Initial_Y_Rho	Angular_Velocities	0 or user-defined	Object used to set the initial angular velocity Y_Rho to either 0 (by default) or to a user-specified value. Note that this value is set at compile time. To set the value at run time, use the reinitialize procedure.
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function multiplies an object of type Angular_Velocities to an object of type Sin_Cos_Ratio returning an object of type Angular_Velocities.
"*"	function	This function multiplies an object of type Angular_Velocities to an object of type Time_Intervals returning an object of type Sin_Cos_Ratio.

3.3.2.4.9.1.9.1.4 LOCAL DATA

Data objects:

The following table describes the data objects created and used by this part:

Name	Type	Description
Prev_X_Rho	Angular_Velocities	This value is the previous X angular velocity used as the lower bound of the integration.
Prev_Y_Rho	Angular_Velocities	This value is the previous Y angular velocity used as the lower bound of the integration.

Exceptions:

3.3.2.4.9.1.9.1.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
package body DCM_Trapezoidal_Integration is

   Prev_X_Rho     : Angular_Velocities := Initial_X_Rho;
   Prev_Y_Rho     : Angular_Velocities := Initial_Y_Rho;

   procedure Reinitialize_Angular_Velocities
                  (X_Rho          : in     Angular_Velocities;
                   Y_Rho          : in     Angular_Velocities) is separate;
```

```
   procedure Perform_Trapezoidal_Integration_of_DCM
               (DC_Matrix       : in out Direction_Cosine_Matrix;
                X_Rho           : in     Angular_Velocities;
                Y_Rho           : in     Angular_Velocities;
                Delta_Time      : in     Time_Intervals) is separate;

end DCM_Trapezoidal_Integration;
```

3.3.2.4.9.1.9.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.9.1.8 LIMITATIONS

None.

3.3.2.4.9.1.9.1.9 LLCSC DESIGN

None.

3.3.2.4.9.1.9.1.10 UNIT DESIGN

3.3.2.4.9.1.9.1.10.1 REINITIALIZE_ANGULAR_VELOCITIES UNIT DESIGN

This unit reinitalizes the angular velocities which are used as the previous angular velocities in Trapezoidal Integration.

3.3.2.4.9.1.9.1.10.1.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.9.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.9.1.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	This type translates into the type of the angular velocity used to integrate the direction cosine matrix.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
X_Rho	Angular_Velocities	In	This object is the X angular velocity that will be used to reinitialize the previous X angular velocity.
Y_Rho	Angular_Velocities	In	This object is the Y angular velocity that will be used to reinitialize the previous Y angular velocity.

3.3.2.4.9.1.9.1.10.1.4 LOCAL DATA

None.

3.3.2.4.9.1.9.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.9.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations.
          DCM_Trapezoidal_Integration)
procedure Reinitialize_Angular_Velocities
             (X_Rho          : in     Angular_Velocities;
              Y_Rho          : in     Angular_Velocities) is

begin

   Prev_X_Rho := X_Rho;
   Prev_Y_Rho := Y_Rho;

end Reinitialize_Angular_Velocities;
```

3.3.2.4.9.1.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF EXTERNAL ELEMENTS:

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data objects:

The following table summarizes the objects required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Prev_X_Rho	Angular_Velocities	Direction_Cosine_Matrix_Operations.DCM_General_Operations.DCM_Trapezoidal_Integration	This object is the angular velocity in the X direction that is used as the previous angular velocity for Trapezoidal integration.
Prev_Y_Rho	Angular_Velocities	Direction_Cosine_Matrix_Operations.DCM_General_Operations.DCM_Trapezoidal_Integration	This object is the angular velocity in the Y direction that is used as the previous angular velocity for Trapezoidal integration.

3.3.2.4.9.1.9.1.10.1.8 LIMITATIONS

None.

3.3.2.4.9.1.9.1.10.2 PERFORM_TRAPEZOIDAL_INTEGRATION_OF_DCM UNIT DESIGN

This part integrates a direction cosine matrix using trapezoidal integration. Only the 2nd and 3rd rows are integrated. The first row must be computed by another function.

3.3.2.4.9.1.9.1.10.2.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.9.1.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.9.1.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	This type translates into the type of the angular velocity used to integrate the direction cosine matrix.
Time_Intervals	floating point type	This type translates into the type of the time parameter used to integrate the direction cosine matrix.
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table summarizes the generic formal objects required by this part:

Name	Type	Value	Description
Initial_X_Rho	Angular_Velocities	0 or user-defined	Object used to set the initial angular velocity X_Rho to either 0 (by default) or to a user-specified value. Note that this value is set at compile time. To set the value at run time, use the reinitialize procedure.
Initial_Y_Rho	Angular_Velocities	0 or user-defined	Object used to set the initial angular velocity Y_Rho to either 0 (by default) or to a user-specified value. Note that this value is set at compile time. To set the value at run time, use the reinitialize procedure.
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function multiplies an object of type Angular_Velocities to an object of type Sin_Cos_Ratio returning an object of type Angular_Velocities.
"*"	function	This function multiplies an object of type Angular_Velocities to an object of type Time_Intervals returning an object of type Sin_Cos_Ratio.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Description
DC_Matrix	This object is the direction cosine matrix to be integrated.
X_Rho	This object is the new X angular velocity that is used as the upper bound in the integration.
Y_Rho	This object is the new Y angular velocity that is used as the upper bound in the integration.
Delta_Time	This object is the time increment since the last angular velocity update.

3.3.2.4.9.1.9.1.10.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Prev_DCM	Direction_Cosine_Matrix	N.A.	This object holds the incoming DCM matrix for use in the integration.
X_Bound_Sum	Angular_Velocities	N.A.	This object is the sum of the lower and upper bounds (angular velocity in X direction) used in the integration.
Y_Bound_Sum	Angular_Velocities	N.A.	This object is the sum of the lower and upper bounds (angular velocity in Y direction) used in the integration.
Del_T_div_2	Time_Intervals	N.A.	This object is the time interval between the previous and current angular velocities - divided by 2 (for use in the integration).

3.3.2.4.9.1.9.1.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.9.1.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations.
          DCM_Trapezoidal_Integration)
procedure Perform_Trapezoidal_Integration_of_DCM
             (DC_Matrix       : in out Direction_Cosine_Matrix;
              X_Rho           : in     Angular_Velocities;
              Y_Rho           : in     Angular_Velocities;
              Delta_Time      : in     Time_Intervals) is

-- ------------------------------------------
-- ---<objects for internal calculations>---
-- ------------------------------------------

   Prev_DCM    : Direction_Cosine_Matrix;
   X_Bound_Sum : Angular_Velocities;
   Y_Bound_Sum : Angular_Velocities;
   Del_T_div_2 : Time_Intervals;

------------------
--begin procedure
------------------

begin

-- -----<copy last two rows of DCM into previous DCM before computing>-----

   Prev_DCM(Row2,Col1) := DC_Matrix(Row2,Col1);
```

```
   Prev_DCM(Row2,Col2) := DC_Matrix(Row2,Col2);
   Prev_DCM(Row2,Col3) := DC_Matrix(Row2,Col3);

   Prev_DCM(Row3,Col1) := DC_Matrix(Row3,Col1);
   Prev_DCM(Row3,Col2) := DC_Matrix(Row3,Col2);
   Prev_DCM(Row3,Col3) := DC_Matrix(Row3,Col3);

-- ---<compute sum of X and Y bounds from old and new angular velocity>---

   X_Bound_Sum := (X_Rho + Prev_X_Rho);
   Y_Bound_Sum := (Y_Rho + Prev_Y_Rho);

-- ---<compute delta time divided by 2 - for algorithm simplification>--

   Del_T_div_2 := Delta_Time * Time_Intervals(0.5);

-- ---<compute new DCM>---

   DC_Matrix(row3,col1) := Prev_DCM(row3,col1) -
                           ( Y_Bound_Sum * Prev_DCM(row3,col3)
                             * Del_T_div_2);

   DC_Matrix(row3,col2) := Prev_DCM(row3,col2) +
                           ( X_Bound_Sum * Prev_DCM(row3,col3)
                             * Del_T_div_2);

   DC_Matrix(row3,col3) := Prev_DCM(row3,col3) +
                           ( Y_Bound_Sum * Prev_DCM(row3,col1) -
                             X_Bound_Sum * Prev_DCM(row3,col2)   )
                           * Del_T_div_2;

   DC_Matrix(row2,col1) := Prev_DCM(row2,col1) -
                           ( Y_Bound_Sum * Prev_DCM(row2,col3)
                             * Del_T_div_2);

   DC_Matrix(row2,col2) := Prev_DCM(row2,col2) +
                           ( X_Bound_Sum * Prev_DCM(row2,col3)
                             * Del_T_div_2);

   DC_Matrix(row2,col3) := Prev_DCM(row2,col3) +
                           ( Y_Bound_Sum * Prev_DCM(row2,col1) -
                             X_Bound_Sum * Prev_DCM(row2,col2)   )
                           * Del_T_div_2;

   Prev_X_Rho := X_Rho;
   Prev_Y_Rho := Y_Rho;

end Perform_Trapezoidal_Integration_of_DCM;
```

3.3.2.4.9.1.9.1.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data objects:

The following table summarizes the objects required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Prev_X_Rho	Angular_Velocities	Direction_Cosine_Matrix_Operations.DCM_General_Operations.DCM_Trapezoidal_Integration	This object is the angular velocity in the X direction that is used as the previous angular velocity for Trapezoidal integration.
Prev_Y_Rho	Angular_Velocities	Direction_Cosine_Matrix_Operations.DCM_General_Operations.DCM_Trapezoidal_Integration	This object is the angular velocity in the Y direction that is used as the previous angular velocity for Trapezoidal integration.

3.3.2.4.9.1.9.1.10.2.8 LIMITATIONS

None.

3.3.2.4.9.1.10 UNIT DESIGN

3.3.2.4.9.1.10.1 DCM_INITIALIZED_FROM_REFERENCE UNIT DESIGN (CATALOG #P288-0)

This function initializes a direction cosine matrix to a reference direction cosine matrix. This part uses the orthonormal properties of the DCM to compute all nine elements of the matrix from four elements of the reference DCM plus the signs from two other reference DCM elements.

This implementation assumes that these four elements are (y,X), (y,Y), (z,X), (z,Y), where xyz and XYZ are the two coordinate frames. The signs are computed from elements (y,Z) and (z,Z).

3.3.2.4.9.1.10.1.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

The following table describes the generic formal types required by this part:

Name	Type	Description
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
SQRT	function	This function computes the square root of a value of the type Sin_Cos_Ratio.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
REF_DCM_2_1	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at row 2, column 1. It represents the direction cosine of the angle between the y-axis and the X-axis.
REF_DCM_2_2	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at row 2, column 2. It represents the direction cosine of the angle between the y-axis and the Y-axis.
REF_DCM_3_1	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at row 3, column 1. It represents the direction cosine of the angle between the z-axis and the X-axis.
REF_DCM_3_2	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at row 3, column 2. It represents the direction cosine of the angle between the z-axis and the Y-axis.
Sign_Of_2_3	INTEGER	In	This value represents the sign of the reference direction cosine element located at row 2, column 3. This value is the sign of the direction cosine of the angle between the y-axis and the Z-axis. The value must equal either -1 or 1, which represents minus or plus, respectively.
Sign_Of_3_3	INTEGER	In	This value represents the sign of the reference direction cosine element located at row 3, column 3. This value is the sign of the direction cosine of the angle between the z-axis and the Z-axis. The value must equal either -1 or 1, which represents minus or plus, respectively.

3.3.2.4.9.1.10.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
DCM_Matrix	Direction_Cosine_Matrix	N.A.	This object is a 3X3 matrix representing the direction consine matrix that is computed from the reference DCM which is passed in.

3.3.2.4.9.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
function DCM_Initialized_From_Reference
                  (REF_DCM_2_1    : Sin_Cos_Ratio;
                   REF_DCM_2_2    : Sin_Cos_Ratio;
                   REF_DCM_3_1    : Sin_Cos_Ratio;
                   REF_DCM_3_2    : Sin_Cos_Ratio;
                   Sign_Of_2_3    : INTEGER;
                   Sign_Of_3_3    : INTEGER)
                  return Direction_Cosine_Matrix is

-- --<direction cosine matrix to be computed>---

   DCM_Matrix     : Direction_Cosine_Matrix;

begin

-- ---<compute new DCM>---

   if Sign_Of_2_3 = 1 then

      DCM_Matrix(Row2,Col3) := SQRT (1.0 - (   REF_DCM_2_1 *
                                               REF_DCM_2_1
                                           +
                                               REF_DCM_2_2 *
                                               REF_DCM_2_2   )
                                    );
   else

      DCM_Matrix(Row2,Col3) := - SQRT (1.0 - (   REF_DCM_2_1 *
                                                 REF_DCM_2_1
                                             +
                                                 REF_DCM_2_2 *
                                                 REF_DCM_2_2   )
                                       );
   end if;

   if Sign_Of_3_3 = 1 then
```

```
      DCM_Matrix(Row3,Col3) := SQRT (1.0 - (   REF_DCM_3_1 *
                                               REF_DCM_3_1
                                           +
                                               REF_DCM_3_2 *
                                               REF_DCM_3_2   )
                                    );
   else
      DCM_Matrix(Row3,Col3) := - SQRT (1.0 - (   REF_DCM_3_1 *
                                                 REF_DCM_3_1
                                             +
                                                 REF_DCM_3_2 *
                                                 REF_DCM_3_2   )
                                       );
   end if;

   DCM_Matrix(Row1,Col1) :=    REF_DCM_2_2 *
                               DCM_Matrix(Row3,Col3)
                            -
                               DCM_Matrix(Row2,Col3) *
                               REF_DCM_3_2;

   DCM_Matrix(Row1,Col2) :=    DCM_Matrix(Row2,Col3) *
                               REF_DCM_3_1
                            -
                               REF_DCM_2_1 *
                               DCM_Matrix(Row3,Col3);

   DCM_Matrix(Row1,Col3) :=    REF_DCM_2_1 *
                               REF_DCM_3_2
                            -
                               REF_DCM_2_2 *
                               REF_DCM_3_1;

   DCM_Matrix(Row2,Col1) := REF_DCM_2_1;
   DCM_Matrix(Row2,Col2) := REF_DCM_2_2;
   DCM_Matrix(Row3,Col1) := REF_DCM_3_1;
   DCM_Matrix(Row3,Col2) := REF_DCM_3_2;

   return DCM_Matrix;

end DCM_Initialized_From_Reference;
```

3.3.2.4.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.1.8 LIMITATIONS

None.

3.3.2.4.9.1.10.2 PERFORM_RECTANGULAR_INTEGRATION_OF_DCM UNIT DESIGN (CATALOG #P290-0)

This procedure integrates a direction cosine matrix using rectangular integration. Only rows 2 and 3 are updated. Row 1 must be updated by another function (using the orthonormal property).

3.3.2.4.9.1.10.2.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point type	This type translates into the type of the angular velocity used to integrate the direction cosine matrix.
Time_Intervals	floating point type	This type translates into the type of the time parameter used to integrate the direction cosine matrix.
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function multiplies an object of type Angular_Velocities to an object of type Time_Intervals returning an object of type Sin_Cos_Ratio.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DC_Matrix	Direction_Cosine_Matrix	in out	This is the direction cosine matrix being integrated.
X_Rho	Angular_Velocities	in	This value represents the angular velocity of the x-axis with respect to the X-axis in the two coordinate frames xyz and XYZ.
Y_Rho	Angular_Velocities	in	This value represents the angular velocity of the y-axis with respect to the Y-axis in the two coordinate frames xyz and XYZ.
Delta_Time	Time_Intervals	in	This value is the time interval over which the integration is to be performed.

3.3.2.4.9.1.10.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
DCM_Incr	Direction_Cosine_Matrix	N.A.	This object is a direction cosine matrix that is used as temporary storage for computed increments.
Y_Rho_Times_Delta_Time	Sin_Cos_Ratio	Y_Rho * Delta_Time	This object holds the angular velocity Y_Rho times the time increment.
X_Rho_Times_Delta_Time	Sin_Cos_Ratio	X_Rho * Delta_Time	This object holds the angular velocity X_Rho times the time increment.

3.3.2.4.9.1.10.2.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
procedure Perform_Rectangular_Integration_of_DCM
          (DC_Matrix  : in out Direction_Cosine_Matrix;
           X_Rho      : in     Angular_Velocities;
           Y_Rho      : in     Angular_Velocities;
           Delta_Time : in     Time_Intervals) is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<DCM for computing increments (temporary) >---

   DCM_Incr                : Direction_Cosine_Matrix;

-- ---< objects for internal calculation >---

   Y_Rho_Times_Delta_Time : Sin_Cos_Ratio := Y_Rho * Delta_Time;
   X_Rho_Times_Delta_Time : Sin_Cos_Ratio := X_Rho * Delta_Time;

-----------------
--begin procedure
-----------------

begin

-- --<compute increments for bottom two rows>--

   DCM_Incr(Row2,Col1) := -DC_Matrix(Row2,Col3) * Y_Rho_Times_Delta_Time;
   DCM_Incr(Row2,Col2) :=  DC_Matrix(Row2,Col3) * X_Rho_Times_Delta_Time;
   DCM_Incr(Row2,Col3) :=  DC_Matrix(Row2,Col1) * Y_Rho_Times_Delta_Time -
                           DC_Matrix(Row2,Col2) * X_Rho_Times_Delta_Time;
   DCM_Incr(Row3,Col1) := -DC_Matrix(Row3,Col3) * Y_Rho_Times_Delta_Time;
   DCM_Incr(Row3,Col2) :=  DC_Matrix(Row3,Col3) * X_Rho_Times_Delta_Time;
   DCM_Incr(Row3,Col3) :=  DC_Matrix(Row3,Col1) * Y_Rho_Times_Delta_Time -
                           DC_Matrix(Row3,Col2) * X_Rho_Times_Delta_Time;

-- --<compute current values of bottom two Rows>--

   DC_Matrix(Row2,Col1) := DC_Matrix(Row2,Col1) + DCM_Incr(Row2,Col1);
   DC_Matrix(Row2,Col2) := DC_Matrix(Row2,Col2) + DCM_Incr(Row2,Col2);
   DC_Matrix(Row2,Col3) := DC_Matrix(Row2,Col3) + DCM_Incr(Row2,Col3);

   DC_Matrix(Row3,Col1) := DC_Matrix(Row3,Col1) + DCM_Incr(Row3,Col1);
   DC_Matrix(Row3,Col2) := DC_Matrix(Row3,Col2) + DCM_Incr(Row3,Col2);
   DC_Matrix(Row3,Col3) := DC_Matrix(Row3,Col3) + DCM_Incr(Row3,Col3);

end Perform_Rectangular_Integration_of_DCM;
```

3.3.2.4.9.1.10.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.2.8 LIMITATIONS

None.

3.3.2.4.9.1.10.3 REORTHONORMALIZE_DCM UNIT DESIGN (CATALOG #P291-0)

This procedure reorthonormalizes (when executed repeatedly) the bottom two rows of the direction cosine matrix. These two rows represent the y and z axes in a direction cosine matrix that transforms data from coordinate frame xyz to frame XYZ. Note that the first row is not updated.

This procedure will not reorthonormalize the DCM after only one iteration. It must be executed repeatedly at a rate based on the precision of the data, the update frequency of the DCM, and other considerations. For example, in a typical application, this function is executed once per minute.

3.3.2.4.9.1.10.3.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DCM_Matrix	Direction_Cosine_Matrix	in	This parameter is the direction cosine matrix to be reorthonormalized.

3.3.2.4.9.1.10.3.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Description
Row2_Dot_Row2	Real	This object is used to store the dot product of row 2 and row 2 of the DCM.
Row3_Dot_Row3	Real	This object is used to store the dot product of row 3 and row 3 of the DCM.
Row2_dot_Row3 Row2_Dot_Row3	Real	This object is used to store the dot product of row 2 and row 3 of the DCM.
Half Row2_Dot_Row3	Sin_Cos_ Ratio	This object is used to store half the dot product of row 2 and row 3 of the DCM.

3.3.2.4.9.1.10.3.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
procedure Reorthonormalize_DCM
          (DCM_Matrix  : in out Direction_Cosine_Matrix) is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<objects for storing dot products>---

   Row2_Dot_Row2      : Real;
   Row3_Dot_Row3      : Real;
   Row2_Dot_Row3      : Real;
   Half_Row2_Dot_Row3 : Sin_Cos_Ratio;

-----------------
--begin procedure
-----------------

begin

   Row2_Dot_Row2 := DCM_Matrix(Row2,Col1) * DCM_Matrix(Row2,Col1) +
                    DCM_Matrix(Row2,Col2) * DCM_Matrix(Row2,Col2) +
                    DCM_Matrix(Row2,Col3) * DCM_Matrix(Row2,Col3);

   Row3_Dot_Row3 := DCM_Matrix(Row3,Col1) * DCM_Matrix(Row3,Col1) +
                    DCM_Matrix(Row3,Col2) * DCM_Matrix(Row3,Col2) +
                    DCM_Matrix(Row3,Col3) * DCM_Matrix(Row3,Col3);
```

```
-- -------------------------
-- --calculate column values
-- -------------------------

   DCM_Matrix(Row2,Col1) := DCM_Matrix(Row2,Col1) *
                            (1.5 - Real(0.5) * Row2_Dot_Row2);

   DCM_Matrix(Row3,Col1) := DCM_Matrix(Row3,Col1) *
                            (1.5 - Real(0.5) * Row3_Dot_Row3);

   DCM_Matrix(Row2,Col2) := DCM_Matrix(Row2,Col2) *
                            (1.5 - Real(0.5) * Row2_Dot_Row2);

   DCM_Matrix(Row3,Col2) := DCM_Matrix(Row3,Col2) *
                            (1.5 - Real(0.5) * Row3_Dot_Row3);

   DCM_Matrix(Row2,Col3) := DCM_Matrix(Row2,Col3) *
                            (1.5 - Real(0.5) * Row2_Dot_Row2);

   DCM_Matrix(Row3,Col3) := DCM_Matrix(Row3,Col3) *
                            (1.5 - Real(0.5) * Row3_Dot_Row3);

-- -------------------------
-- --<compute Rows 2 thru 3>
-- -------------------------

   Row2_Dot_Row3 := DCM_Matrix(Row2,Col1) * DCM_Matrix(Row3,Col1) +
                    DCM_Matrix(Row2,Col2) * DCM_Matrix(Row3,Col2) +
                    DCM_Matrix(Row2,Col3) * DCM_Matrix(Row3,Col3);

   Half_Row2_dot_Row3 := 0.5 * Row2_dot_Row3;

   DCM_Matrix(Row2,Col1) := DCM_Matrix(Row2,Col1) -
                            (Half_Row2_Dot_Row3 * DCM_Matrix(Row3,Col1));

   DCM_Matrix(Row3,Col1) := DCM_Matrix(Row3,Col1) -
                            (Half_Row2_Dot_Row3 * DCM_Matrix(Row2,Col1));

   DCM_Matrix(Row2,Col2) := DCM_Matrix(Row2,Col2) -
                            (Half_Row2_Dot_Row3 * DCM_Matrix(Row3,Col2));

   DCM_Matrix(Row3,Col2) := DCM_Matrix(Row3,Col2) -
                            (Half_Row2_Dot_Row3 * DCM_Matrix(Row2,Col2));

   DCM_Matrix(Row2,Col3) := DCM_Matrix(Row2,Col3) -
                            (Half_Row2_Dot_Row3 * DCM_Matrix(Row3,Col3));

   DCM_Matrix(Row3,Col3) := DCM_Matrix(Row3,Col3) -
                            (Half_Row2_Dot_Row3 * DCM_Matrix(Row2,Col3));

end Reorthonormalize_DCM;
```

3.3.2.4.9.1.10.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.3.8 LIMITATIONS

None.

3.3.2.4.9.1.10.4 FRAME_MISALIGNMENT UNIT DESIGN (CATALOG #P292-0)

This unit computes the rotation of the computed XYZ frame with respect to a reference XYZ frame given the direction cosine matrix of the computed XYZ frame and the direction cosine matrix of the reference XYZ frame. Each rotation angle provided by this part is approximated as the sine of the rotation angle.

3.3.2.4.9.1.10.4.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.4.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.4.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.
Rotation_Indices	discrete type	Data type which translates into the indexing elements of a rotation angle vector.
Rotation_Angles	floating point	Type which translates into the type of the elements of a rotation angle vector.
Rotation_Angle_Vec	1X3 matrix (vector)	Type representing a rotation angle vector.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.
X	Rotation _Indices	'FIRST	Object to be used as an index representing the first element of the rotation angle vector.
Y	Rotation _Indices	SUCC 'FIRST	Object to be used as an index representing the second element of the rotation angle vector.
Z	Rotation _Indices	'LAST	Object to be used as an index representing the third element of the rotation angle vector.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function multiplies an object of type Sin_Cos_Ratio to an object of type Sin_Cos_Ratio returning an object of type Rotation_Angles.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DCM_Matrix	Direction_Cosine_Matrix	In	This parameter is the current active direction cosine matrix.
REF_DC_Matrix	Direction_Cosine_Matrix	In	This parameter is the reference direction cosine matrix. The misalignment angles are computed by determining the angular differences between this DCM and the active DCM.

3.3.2.4.9.1.10.4.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Rot_Angle	Rotation_Angle_Vec	N.A.	This object is the rotation angle vector that is returned by the function.

3.3.2.4.9.1.10.4.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.4.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
function Frame_Misalignment
              (DCM_Matrix     : Direction_Cosine_Matrix;
               REF_DC_Matrix  : Direction_Cosine_Matrix)
              return Rotation_Angle_Vec is
```

```
-- ---------------------
-- --declaration section
-- ---------------------

-- ---<the rotation angle vector that is returned>---

   Rot_Angle    : Rotation_Angle_Vec;

----------------
--begin function
----------------

begin

   Rot_Angle(X) := DCM_Matrix(Row1,Col2) * REF_DC_Matrix(Row1,Col3) +
                   DCM_Matrix(Row2,Col2) * REF_DC_Matrix(Row2,Col3) +
                   DCM_Matrix(Row3,Col2) * REF_DC_Matrix(Row3,Col3);

   Rot_Angle(Y) := DCM_Matrix(Row1,Col3) * REF_DC_Matrix(Row1,Col1) +
                   DCM_Matrix(Row2,Col3) * REF_DC_Matrix(Row2,Col1) +
                   DCM_Matrix(Row3,Col3) * REF_DC_Matrix(Row3,Col1);

   Rot_Angle(Z) := DCM_Matrix(Row1,Col1) * REF_DC_Matrix(Row1,Col2) +
                   DCM_Matrix(Row2,Col1) * REF_DC_Matrix(Row2,Col2) +
                   DCM_Matrix(Row3,Col1) * REF_DC_Matrix(Row3,Col2);

   return Rot_Angle;

end Frame_Misalignment;
```

3.3.2.4.9.1.10.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.4.8 LIMITATIONS

None.

3.3.2.4.9.1.10.5 ALIGNED_DCM_MATRIX UNIT DESIGN (CATALOG #P293-0)

This part modifies the bottom two rows (y and z) of the direction cosine matrix so that the current coordinate frame is aligned to a true coordinate frame. This part assumes a coordinate frame representation of xyz to XYZ, where xyz is the coordinate frame noted as "true". NOTE: Only rows 2 and 3 are aligned. Row 1 must be computed separately.

3.3.2.4.9.1.10.5.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.5.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.5.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.
Rotation_Indices	discrete type	Data type which translates into the indexing elements of a rotation angle vector.
Rotation_Angles	floating point	Type which translates into the type of the elements of a rotation angle vector.
Rotation_Angle_Vec	1X3 matrix (vector)	Type representing a rotation angle vector.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.
X	Rotation_Indices	'FIRST	Object to be used as an index representing the first element of the rotation angle vector.
Y	Rotation_Indices	SUCC 'FIRST	Object to be used as an index representing the second element of the rotation angle vector.
Z	Rotation_Indices	'LAST	Object to be used as an index representing the third element of the rotation angle vector.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function multiplies an object of type Sin_Cos_Ratio to an object of type Rotation_Angles returning an object of type Sin_Cos_Ratio.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DCM_Matrix	Direction_Cosine_Matrix	In	This parameter is the current active direction cosine matrix.
Rotation_Angle	Rotation_Angle_Vec	In	This parameter represents the rotation angles used to align the DCM matrix.

3.3.2.4.9.1.10.5.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
DCM_New	Direction_Cosine_Matrix	N.A.	This object is the direction cosine matrix that is computed and returned.

3.3.2.4.9.1.10.5.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.5.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
function Aligned_DCM_Matrix
         (DCM_Matrix     : Direction_Cosine_Matrix;
          Rotation_Angle : Rotation_Angle_Vec)
         return Direction_Cosine_Matrix is

-- ----------------------
-- --declaration section
```

```
-- ---------------------

-- ---<computed DCM to be returned>---

   DCM_New : Direction_Cosine_Matrix;

-----------------
--begin function
-----------------

begin

   DCM_New(Row2,Col1) := DCM_Matrix(Row2,Col1) + DCM_Matrix(Row2,Col3) *
                         Rotation_Angle(Y);

   DCM_New(Row2,Col2) := DCM_Matrix(Row2,Col2) - DCM_Matrix(Row2,Col3) *
                         Rotation_Angle(X);

   DCM_New(Row2,Col3) := DCM_Matrix(Row2,Col3) - DCM_Matrix(Row2,Col1) *
                         Rotation_Angle(Y) +
                         DCM_Matrix(Row2,Col2) * Rotation_Angle(X);

   DCM_New(Row3,Col1) := DCM_Matrix(Row3,Col1) + DCM_Matrix(Row3,Col3) *
                         Rotation_Angle(Y);

   DCM_New(Row3,Col2) := DCM_Matrix(Row3,Col2) - DCM_Matrix(Row3,Col3) *
                         Rotation_Angle(X);

   DCM_New(Row3,Col3) := DCM_Matrix(Row3,Col3) - DCM_Matrix(Row3,Col1) *
                         Rotation_Angle(Y) +
                         DCM_Matrix(Row3,Col2) * Rotation_Angle(X);

-- ---<set first row equal to original matrix>--
-- ---<NOTE:  The first row is now INVALID data>--

  DCM_New(Row1,Col1) := DCM_Matrix(Row1,Col1);
  DCM_New(Row1,Col2) := DCM_Matrix(Row1,Col2);
  DCM_New(Row1,Col3) := DCM_Matrix(Row1,Col3);

  return DCM_New;

end Aligned_DCM_Matrix;
```

3.3.2.4.9.1.10.5.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.5.8 LIMITATIONS

None.

3.3.2.4.9.1.10.6 COMPUTE_FIRST_ROW_FROM_ORTHONORMAL UNIT DESIGN (CATALOG #P294-0)

This part computes the first row of the direction cosine matrix from the second and third rows of the same matrix using the orthonormal property.

In many applications, the second and third rows are updated at a higher rate than the first row. Because of this, this function has been designed as a separate part.

3.3.2.4.9.1.10.6.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.6.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.6.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
DCM_Matrix	Direction_Cosine_Matrix	In Out	This parameter is the current active direction cosine matrix.

3.3.2.4.9.1.10.6.4 LOCAL DATA

None.

3.3.2.4.9.1.10.6.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.6.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
procedure Compute_First_Row_From_Orthonormal
            (DCM_Matrix      : in out Direction_Cosine_Matrix) is

begin

   DCM_Matrix(Row1,Col1) :=   DCM_Matrix(Row2,Col2) * DCM_Matrix(Row3,Col3)
                            - DCM_Matrix(Row2,Col3) * DCM_Matrix(Row3,Col2);

   DCM_Matrix(Row1,Col2) :=   DCM_Matrix(Row2,Col3) * DCM_Matrix(Row3,Col1)
                            - DCM_Matrix(Row2,Col1) * DCM_Matrix(Row3,Col3);

   DCM_Matrix(Row1,Col3) :=   DCM_Matrix(Row2,Col1) * DCM_Matrix(Row3,Col2)
                            - DCM_Matrix(Row2,Col2) * DCM_Matrix(Row3,Col1);

end Compute_First_Row_From_Orthonormal;
```

3.3.2.4.9.1.10.6.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.6.8 LIMITATIONS

None.

3.3.2.4.9.1.10.7 DCM_FROM_QUATERNION UNIT DESIGN (CATALOG #P295-0)

This part computes the direction cosine matrix that transforms data from coordinate frame xyz to XYZ given the unit quaternion that rotates the XYZ frame into the xyz frame.

3.3.2.4.9.1.10.7.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.1.10.7.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.1.10.7.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Row_Indices	discrete type	Data type which translates into the row indexing of the direction cosine matrix.
Col_Indices	discrete type	Data type which translates into the column indexing of the direction cosine matrix.
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
Direction_Cosine_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.
Quaternion_Indices	discrete type	Data type which translates into the indexing elements which index the quaternion.
Quaternion_Vector	1X4 matrix	Type representing the unit quaternion which rotates the XYZ frame into the xyz frame.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Row1	Row_Indices	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Row2	Row_Indices	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Row3	Row_Indices	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
Col1	Col_Indices	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
Col2	Col_Indices	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Col3	Col_Indices	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.
Q0	Quaternion _Indices	'FIRST	Object to be used as an index representing the first element of the quaternion.
Q1	Quaternion _Indices	SUCC 'FIRST	Object to be used as an index representing the second element of the quaternion.
Q2	Quaternion _Indices	PRED 'LAST	Object to be used as an index representing the third element of the quaternion.
Q3	Quaternion _Indices	'LAST	Object to be used as an index representing the fourth element of the quaternion.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Quaternion	Quaternion_Vectors	In	This object represents the unit quaternion which rotates XYZ into xyz.

3.3.2.4.9.1.10.7.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Q0_Sqr	Sin_Cos_Ratio	N.A.	This object temporarily hold the square of quaternion element q0.
Q1_Sqr	Sin_Cos_Ratio	N.A.	This object temporarily hold the square of quaternion element q1.
Q2_Sqr	Sin_Cos_Ratio	N.A.	This object temporarily hold the square of quaternion element q2.
Q3_Sqr	Sin_Cos_Ratio	N.A.	This object temporarily hold the square of quaternion element q3.
DCM	Direction_Cosine_Matrix	N.A.	This object is the direction cosine matrix that is computed and returned.

3.3.2.4.9.1.10.7.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.1.10.7.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.DCM_General_Operations)
function DCM_From_Quaternion
            (Quaternion : Quaternion_Vectors)
            return Direction_Cosine_Matrix is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<objects to hold the squares of quaternions>---

   Q0_Sqr  : Sin_Cos_Ratio;
   Q1_Sqr  : Sin_Cos_Ratio;
```

```
   Q2_Sqr  : Sin_Cos_Ratio;
   Q3_Sqr  : Sin_Cos_Ratio;

-- ---<the DCM to be returned>---

   DCM     : Direction_Cosine_Matrix;

----------------
--begin function
----------------

begin

-- ----- <compute squares of quaternions> ------

   Q0_Sqr := Quaternion(q0) * Quaternion(q0);
   Q1_Sqr := Quaternion(q1) * Quaternion(q1);
   Q2_Sqr := Quaternion(q2) * Quaternion(q2);
   Q3_Sqr := Quaternion(q3) * Quaternion(q3);


-- ----- <compute direction cosines> ---------

   DCM(Row1,Col1) := Q0_Sqr + Q1_Sqr - Q2_Sqr - Q3_Sqr;
   DCM(Row2,Col2) := Q0_Sqr - Q1_Sqr + Q2_Sqr - Q3_Sqr;
   DCM(Row3,Col3) := Q0_Sqr - Q1_Sqr - Q2_Sqr + Q3_Sqr;

   DCM(Row2,Col1) := ( (Quaternion(q0) * Quaternion(q3))
                      +(Quaternion(q1) * Quaternion(q2)) )
                     * 2.0;

   DCM(Row3,Col1) := ( (Quaternion(q1) * Quaternion(q3))
                      -(Quaternion(q0) * Quaternion(q2)) )
                     * 2.0;

   DCM(Row1,Col2) := ( (Quaternion(q1) * Quaternion(q2))
                      -(Quaternion(q0) * Quaternion(q3)) )
                     * 2.0;

   DCM(Row3,Col2) := ( (Quaternion(q0) * Quaternion(q1))
                      +(Quaternion(q2) * Quaternion(q3)) )
                     * 2.0;

   DCM(Row1,Col3) := ( (Quaternion(q0) * Quaternion(q2))
                      +(Quaternion(q1) * Quaternion(q3)) )
                     * 2.0;

   DCM(Row2,Col3) := ( (Quaternion(q2) * Quaternion(q3))
                      -(Quaternion(q0) * Quaternion(q1)) )
                     * 2.0;

   return DCM;

end DCM_From_Quaternion;
```

3.3.2.4.9.1.10.7.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.1.10.7.8 LIMITATIONS

None.

3.3.2.4.9.2 CNE_OPERATIONS PACKAGE DESIGN (CATALOG #P296-0)

This package contains all functions and procedures that specifically apply to a CNE direction cosine matrix. A CNE DCM is a 3X3 matrix that is used to transform data between the Navigation coordinate frame and the Earth coordinate frame. The Navigation frame assumes the convention "East, North, Up", and the Earth frame assumes the convention "Greenwich, Right, Polar". The elements of this matrix are direction cosines of angles between specific axes of the two coordinate frames.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.9.2.1 REQUIREMENTS ALLOCATION

The following table summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
CNE_Initialized_From_Reference	N/A
Reorthonormalize_CNE	N/A
Compute_First_Row_of_CNE_From_Orthonormal	N/A
CNE_Initialized_From_Earth_Position	R32
Perform_Trapezoidal_Integration_of_CNE	N/A
Perform_Rectangular_Integration_of_CNE	N/A
Frame_Misalignment_of_CNE	N/A
Aligned_CNE_Matrix	N/A
CNE_From_Quaternion	N/A

3.3.2.4.9.2.2 LOCAL ENTITIES DESIGN

Subprograms:

The following table describes the subprograms in this part. The first two subprograms are instantiations of parts from DCM_General_Operations.

Name	Type	Description
CNE_Initialized_From_Reference	function	This function initializes a CNE matrix to a reference CNE matrix.
Reorthonormalize_CNE	procedure	This procedure reorthonormalizes a CNE matrix.
Compute_First_Row_of_CNE_From_Orthonormal	procedure	This procedure computes the first row of a CNE matix using the orthonormal property.
CNE_Initialized_From_Earth_Position	generic function	This function initializes the CNE matrix from the latitude, longitude, and wander angle of the missile location.

3.3.2.4.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Axes	discrete type	Data type which translates into the row indexing of the direction cosine matrix. This type should be equivalent (conceptually) to "Greenw, Right, Polar".
Navigation_Axes	discrete type	Data type which translates into the column indexing of the direction cosine matrix. This type should be equivalent (conceptually) to "East, North, Up".
Sin_Cos_Ratio	floating point	Type which translates into the type of the elements of the direction cosine matrix.
CNE_Matrix	3X3 matrix	Type representing a direction cosine matrix indexed by the column and row types described above with elements of type Sin_Cos_Ratio.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
Greenw	Earth_Axes	'FIRST	Object to be used as an index representing the first row of the direction cosine matrix. This object indexes the direction cosines of the angles between the x-axis and the XYZ axes.
Right	Earth_Axes	SUCC 'FIRST	Object to be used as an index representing the second row of the direction cosine matrix. This object indexes the direction cosines of the angles between the y-axis and the XYZ axes.
Polar	Earth_Axes	'LAST	Object to be used as an index representing the third row of the direction cosine matrix. This object indexes the direction cosines of the angles between the z-axis and the XYZ axes.
East	Navigation _Axes	'FIRST	Object to be used as an index representing the first column of the direction cosine matrix. This object indexes the direction cosines of the angles between the X-axis and the xyz axes.
North	Navigation _Axes	SUCC 'FIRST	Object to be used as an index representing the second column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Y-axis and the xyz axes.
Up	Navigation _Axes	'LAST	Object to be used as an index representing the third column of the direction cosine matrix. This object indexes the direction cosines of the angles between the Z-axis and the xyz axes.

FORMAL PARAMETERS:

The following table describes subprogram CNE_Initialized_From_Reference's formal parameters:

Name	Type	Mode	Description
REF_CNE_2_1	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at RIGHT, EAST. It represents the direction cosine of the angle between the y-axis and the X-axis.
REF_CNE_2_2	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at RIGHT, NORTH. It represents the direction cosine of the angle between the y-axis and the Y-axis.
REF_CNE_3_1	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at POLAR, EAST. It represents the direction cosine of the angle between the z-axis and the X-axis.
REF_CNE_3_2	Sin_Cos_Ratio	In	This value is the reference direction cosine element located at POLAR, NORTH. It represents the direction cosine of the angle between the z-axis and the Y-axis.
Sign_Of_2_3	INTEGER	In	This value represents the sign of the reference direction cosine element located at RIGHT, column 3. This value is the sign of the direction cosine of the angle between the y-axis and the Z-axis. The value must equal either -1 or 1, which represents minus or plus, respectively.
Sign_Of_3_3	INTEGER	In	This value represents the sign of the reference direction cosine element located at POLAR, column 3. This value is the sign of the direction cosine of the angle between the z-axis and the Z-axis. The value must equal either -1 or 1, which represents minus or plus, respectively.

The following table describes subprogram Reorthonormalize_CNE's formal parameters:

Name	Type	Mode	Description
CNE	CNE_Matrices	in	This parameter is the direction cosine matrix to be reorthonormalized.

3.3.2.4.9.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
CNE_Matrices	3X3	N.A.	This type is a type representing a DCM derived from the coordinate frames of the Earth and Navigation frames. The earth frame axes are assumed to be "Greenwich, Right, Polar", and the navigation frame axes are assumed to be "North, East, Up".

3.3.2.4.9.2.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations)
package body CNE_Operations is

   package DCM_GEN_PKG renames
                  Direction_Cosine_Matrix_Operations.DCM_General_Operations;

-- ------------------------------------------------------------------
-- --<instantiation of a units from "DCM_General_Operations" with CNE
-- -- specific parameters applied to the generics>
-- ------------------------------------------------------------------

   function Initialize_From_Ref is new
               DCM_GEN_PKG.DCM_Initialized_From_Reference
                  (Row_Indices            => Earth_Axes,
                   Col_Indices            => Navigation_Axes,
                   Sin_Cos_Ratio          => Sin_Cos_Ratio,
                   Direction_Cosine_Matrix => CNE_Matrices);

   procedure Reorthonormalize is new
                DCM_GEN_PKG.Reorthonormalize_DCM
                   (Row_Indices            => Earth_Axes,
                    Col_Indices            => Navigation_Axes,
                    Sin_Cos_Ratio          => Sin_Cos_Ratio,
                    Direction_Cosine_Matrix => CNE_Matrices,
                    Real                   => Real);

   procedure Compute_First_Row is new
                DCM_GEN_PKG.Compute_First_Row_From_Orthonormal
                   (Row_Indices            => Earth_Axes,
```

```
                    Col_Indices             => Navigation_Axes,
                    Sin_Cos_Ratio           => Sin_Cos_Ratio,
                    Direction_Cosine_Matrix => CNE_Matrices);

-- ----------------
-- --separate parts
-- ----------------

   function CNE_Initialized_From_Earth_Position
                           (Wander_Angle : Angles;
                            Latitude     : Earth_Position;
                            Longitude    : Earth_Position)
                            return CNE_Matrices is separate;

   package body CNE_Integration is separate;

   package body Alignment_Parts is separate;

   package body CNE_From_Quaternion is separate;

-- ------------------------------------------------------
-- --routines acting as interfaces to instantiated routines
-- ------------------------------------------------------

   function CNE_Initialized_From_Reference
               (Ref_CNE_2_1    : Sin_Cos_Ratio;
                Ref_CNE_2_2    : Sin_Cos_Ratio;
                Ref_CNE_3_1    : Sin_Cos_Ratio;
                Ref_CNE_3_2    : Sin_Cos_Ratio;
                Sign_Of_2_3    : INTEGER;
                Sign_Of_3_3    : INTEGER)
               return CNE_Matrices is
   begin
      return Initialize_From_Ref
                (Ref_DCM_2_1 => Ref_CNE_2_1,
                 Ref_DCM_2_2 => Ref_CNE_2_2,
                 Ref_DCM_3_1 => Ref_CNE_3_1,
                 Ref_DCM_3_2 => Ref_CNE_3_2,
                 Sign_Of_2_3 => Sign_Of_2_3,
                 Sign_Of_3_3 => Sign_Of_3_3);
   end CNE_Initialized_From_Reference;

   procedure Reorthonormalize_CNE (CNE : in out CNE_Matrices) is
   begin
      Reorthonormalize (CNE);
   end Reorthonormalize_CNE;

   procedure Compute_First_Row_of_CNE_From_Orthonormal
               (CNE : in out CNE_Matrices) is
   begin
      Compute_First_Row (CNE);
   end Compute_First_Row_of_CNE_From_Orthonormal;

end CNE_Operations;
```

3.3.2.4.9.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.2.8 LIMITATIONS

None.

3.3.2.4.9.2.9 LLCSC DESIGN

3.3.2.4.9.2.9.1 CNE_INTEGRATION PACKAGE DESIGN (CATALOG #P298-0)

This generic package contains procedures that integrate a CNE direction cosine matrix. The first two procedures initialize and integrate a CNE using trapezoidal integration. The last procedure integrates a CNE using rectangular integration. Note that the first row is not computed in the integration. It must be computed by another function.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.9.2.9.1.1 REQUIREMENTS ALLOCATION

The following table summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
Perform_Trapezoidal_Integration_of_CNE	N/A
Perform_Rectangular_Integration_of_CNE	N/A

3.3.2.4.9.2.9.1.2 LOCAL ENTITIES DESIGN

Packages:

For "Perform_Trapezoidal_Integration_of_CNE", the package "Integrate_Trap" is created and maintained.

Subprograms:

For "Perform_Rectangular_Integration_of_CNE", the procedure "Integrate_Rect" is created and maintained.

3.3.2.4.9.2.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Angular_Velocities	floating point	Data type that translates into the type of a component of the angular velocity in a given reference frame.
Time_Intervals	floating point	Data type that translates into the type of an object that represents a time interval (delta time).

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Description
Initial_East_Rho	Angular_Velocities	This object can be used to initialize the East component of angular velocity (for trapezoidal integration).
Initial_North_Rho	Angular_Velocities	This object can be used to initialize the North component of angular velocity (for trapezoidal integration).

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function computes the product of an object of type Angular_Velocity and an object of type Time_Intervals producing an object of type Sin_Cos_Ratio.
"*"	function	This function computes the product of an object of type Angular_Velocity and an object of type Sin_Cos_Ratio producing an object of type Angular_Velocities.

FORMAL PARAMETERS:

The following table describes procedure "Perform_Trapezoidal_Integration_of_CNE"'s formal parameters:

Name	Type	Mode	Description
CNE	CNE_Matrices	In Out	This parameter is the direction cosine matrix that is integrated.
East_Rho	Angular_Velocities	In	This value is the East component of angular velocity.
North_Rho	Angular_Velocities	In	This value is the North component of angular velocity.
Delta_Time	Time_Intervals	In	This value is the time interval which equals the time since the last integration.

The following table describes procedure "Reinit_Ang_Vel_For_Trapez_Integ_of_-CNE"'s formal parameters:

Name	Type	Mode	Description
East_Rho	Angular_Velocities	In	This value is the East component of angular velocity to be used for initialization.
North_Rho	Angular_Velocities	In	This value is the North component of angular velocity to be used for initialization.

The following table describes procedure "Perform_Rectangular_Integration_of_-CNE"'s formal parameters:

Name	Type	Mode	Description
CNE	CNE_Matrices	In Out	This parameter is the direction cosine matrix that is integrated.
East_Rho	Angular_Velocities	In	This value is the East component of angular velocity.
North_Rho	Angular_Velocities	In	This value is the North component of angular velocity.
Delta_Time	Time_Intervals	In	This value is the time interval which equals the time since the last integration.

3.3.2.4.9.2.9.1.4 LOCAL DATA

None.

3.3.2.4.9.2.9.1.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.2.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.CNE_Operations)
package body CNE_Integration is

-- ----------------------
-- --local instantiations
-- ----------------------

-- --<instantiation of a units from "DCM_General_Operations" with CNE
-- -- specific parameters applied to the generics>---

   package Integrate_Trap is new
             DCM_GEN_PKG.DCM_Trapezoidal_Integration
               (Angular_Velocities      => Angular_Velocities,
                Time_Intervals          => Time_Intervals,
                Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => CNE_Matrices,
                Initial_X_Rho           => Initial_East_Rho,
                Initial_Y_Rho           => Initial_North_Rho);

   procedure Integrate_Rect is new
             DCM_GEN_PKG.Perform_Rectangular_Integration_of_DCM
               (Angular_Velocities      => Angular_Velocities,
                Time_Intervals          => Time_Intervals,
                Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => CNE_Matrices);

-- ------------------------------------------------------
-- --routines acting as interfaces to instantiated routines
-- ------------------ -----------------------------------

-- -------[Trapezoidal Integration]---------

   procedure Perform_Trapezoidal_Integration_of_CNE
               (CNE            : in out CNE_Matrices;
                East_Rho       : in     Angular_Velocities;
                North_Rho      : in     Angular_Velocities;
                Delta_Time     : in     Time_Intervals) is
   begin
      Integrate_Trap.Perform_Trapezoidal_Integration_of_DCM
```

```
                              (CNE, East_Rho, North_Rho, Delta_Time);
   end Perform_Trapezoidal_Integration_of_CNE;


   procedure Reinit_Ang_Vel_for_Trapez_Integ_of_CNE
               (East_Rho     : in     Angular_Velocities;
                North_Rho    : in     Angular_Velocities) is
   begin
      Integrate_Trap.Reinitialize_Angular_Velocities
                              (East_Rho, North_Rho);
   end Reinit_Ang_Vel_for_Trapez_Integ_of_CNE;


-- -------[Rectangular Integration]---------

   procedure Perform_Rectangular_Integration_of_CNE
             (CNE        : in out CNE_Matrices;
              East_Rho   : in     Angular_Velocities;
              North_Rho  : in     Angular_Velocities;
              Delta_Time : in     Time_Intervals) is
   begin
      Integrate_Rect (CNE, East_Rho, North_Rho, Delta_Time);
   end Perform_Rectangular_Integration_of_CNE;


end CNE_Integration;
```

3.3.2.4.9.2.9.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

Name	Type	Source	Description
DCM_General_Operations	package	Direction_Cosine_Matrix_Operations	This package contains general operations for direction cosine matrices. CNE_Integration instantiates functions and procedures from this package.
DCM_Trapezoidal_Integration_of_DCM	package	DCM_General_Operations	This package contains 2 procedures; the first reinitializes the angular velocities for trapezoidal integration, and the second performs the integration.

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
CNE_Matrices	3X3 matrix	CNE_Operations	Type representing a direction cosine matrix indexed by the column and row types representing the navigation and earth frame.

3.3.2.4.9.2.9.1.8 LIMITATIONS

None.

3.3.2.4.9.2.9.1.9 LLCSC DESIGN

None.

3.3.2.4.9.2.9.1.10 UNIT DESIGN

None.

3.3.2.4.9.2.9.2 ALIGNMENT_PARTS PACKAGE DESIGN (CATALOG #P299-0)

This package contains two functions. The first function computes the rotation angles between the CNE and a reference direction cosine matrix. The second function rotates the CNE matrix into alignment by using the rotation angles. The second function only computes the second and third row of the CNE matrix. The first row must be updated separately.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.9.2.9.2.1 REQUIREMENTS ALLOCATION

The following table summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
Frame_Misalignment_of_CNE	N/A
Aligned_CNE_Matrix	N/A

3.3.2.4.9.2.9.2.2 LOCAL ENTITIES DESIGN

Packages:

For "Perform_Trapezoidal_Integration_of_CNE", the package "Integrate_Trap" is created and maintained.

Subprograms:

For "Frame_Misalignment_of_CNE", the function "Computed _Frame_Misalignment" is created and maintained. For "Aligned_CNE_Matrix", the function "Align_CNE_-Matrix" is created and maintained.

3.3.2.4.9.2.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Rotation _Indices	discrete type	Data type which translates into the indexing elements of a rotation angle vector.
Rotation _Angles	floating point	Type which translates into the type of the elements of a rotation angle vector.
Rotation _Angle _Vec	1X3 matrix (vector)	Type representing a rotation angle vector.

Data objects:

The following table describes the generic formal objects required by this part:

Name	Type	Value	Description
X	Rotation _Indices	'FIRST	Object to be used as an index representing the first element of the rotation angle vector.
Y	Rotation _Indices	SUCC 'FIRST	Object to be used as an index representing the second element of the rotation angle vector.
Z	Rotation _Indices	'LAST	Object to be used as an index representing the third element of the rotation angle vector.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
"*"	function	This function computes the product of an object of type Sin_Cos_Ratio and an object of type Rotation_Angles producing an object of type Sin_Cos_Ratio.
"*"	function	This function computes the product of an object of type Sin_Cos_Ratio and an object of type Sin_Cos_Ratio producing an object of type Rotation_Angles.

FORMAL PARAMETERS:

The following table describes function "Frame_Misalignment_of_CNE"'s formal parameters:

Name	Type	Mode	Description
CNE	CNE_Matrices	In	This parameter is the active direction cosine matrix (of the missile).
REF_DC_Matrix	CNE_Matrices	In	This parameter is the reference direction cosine matrix.

The following table describes function "Aligned_CNE_Matrix"'s formal parameters:

Name	Type	Mode	Description
CNE	CNE_Matrices	In	This parameter is the active direction cosine matrix (of the missile).
Rotation_Angle	Rotation_Angle_Vec	In	This parameter is the rotation angles to be used to align the DCM.

3.3.2.4.9.2.9.2.4 LOCAL DATA

None.

3.3.2.4.9.2.9.2.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.2.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.CNE_Operations)
package body Alignment_Parts is

-- ----------------------
-- --local instantiations
-- ----------------------

---<instantiation of a unit from "DCM_General_Operations" with CNE
--  specific parameters applied to the generics>---

   function Computed_Frame_Misalignment is new
            DCM_GEN_PKG.Frame_Misalignment
               (Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => CNE_Matrices,
                Rotation_Indices        => Rotation_Indices,
                Rotation_Angles         => Rotation_Angles,
                Rotation_Angle_Vec      => Rotation_Angle_Vec);

   function Align_CNE_Matrix is new
             DCM_GEN_PKG.Aligned_DCM_Matrix
               (Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => CNE_Matrices,
                Rotation_Indices        => Rotation_Indices,
                Rotation_Angles         => Rotation_Angles,
                Rotation_Angle_Vec      => Rotation_Angle_Vec);

-- ------------------------------------------------------
-- --routines acting as interfaces to instantiated routines
-- ------------------------------------------------------

-- -------[Frame Misalignment]----------

   function Frame_Misalignment_of_CNE
               (CNE            : CNE_Matrices;
                REF_DC_Matrix  : CNE_Matrices)
               return Rotation_Angle_Vec is
   begin
      return Computed_Frame_Misalignment (CNE, REF_DC_Matrix);
   end Frame_Misalignment_of_CNE;

-- -------[Align CNE Matrix]----------

   function Aligned_CNE_Matrix
               (CNE            : CNE_Matrices;
                Rotation_Angle : Rotation_Angle_Vec)
               return CNE_Matrices is
   begin
      return Align_CNE_Matrix (CNE, Rotation_Angle);
   end Aligned_CNE_Matrix;
```

```
end Alignment_Parts;
```

3.3.2.4.9.2.9.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

The following table summarizes the external packages required by this part:

Name	Type	Source	Description
DCM_General_Operations	package	Direction_Cosine_Matrix_Operations	This package contains general operations for direction cosine matrices. Alignment_Parts instantiates functions and procedures from this package.

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
CNE_Matrices	3X3 matrix	CNE_Operations	Type representing a direction cosine matrix indexed by the column and row types representing the navigation and earth frame.

3.3.2.4.9.2.9.2.8 LIMITATIONS

None.

3.3.2.4.9.2.9.2.9 LLCSC DESIGN

None.

3.3.2.4.9.2.9.2.10 UNIT DESIGN

None.

3.3.2.4.9.2.9.3 CNE_FROM_QUATERNION PACKAGE DESIGN (CATALOG #P300-0)

This package contains a function which initializes the CNE matrix using a quaternion.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.2.4.9.2.9.3.1 REQUIREMENTS ALLOCATION

The following table summarizes the allocation of CAMP requirements to this part:

Name	Requirements Allocation
CNE_From_Quaternion	N/A

3.3.2.4.9.2.9.3.2 LOCAL ENTITIES DESIGN

Subprograms:

The function "Computed_CNE" is created and maintained by this part.

3.3.2.4.9.2.9.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Type	Description
Quaternion_Indices	discrete type	Data type which translates into the indexing elements which index the quaternion.
Quaternion_Vector	1X4 matrix	Type representing the unit quaternion which rotates the XYZ frame into the xyz frame.

Data objects:

The following table summarizes the generic formal objects required by this part:

Name	Type	Value	Description
Q0	Quaternion_Indices	'FIRST	Object to be used as an index representing the first element of the quaternion.
Q1	Quaternion_Indices	SUCC('FIRST)	Object to be used as an index representing the second element of the quaternion.
Q2	Quaternion_Indices	PRED('LAST)	Object to be used as an index representing the third element of the quaternion.
Q3	Quaternion_Indices	'LAST	Object to be used as an index representing the fourth element of the quaternion.

FORMAL PARAMETERS:

The following describes the formal parameters for the function "Compute_CNE":

Name	Type	Mode	Description
Quaternion	Quaternion_Vectors	In	This object represents the unit quaternion which rotates XYZ into xyz.

3.3.2.4.9.2.9.3.4 LOCAL DATA

None.

3.3.2.4.9.2.9.3.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.2.9.3.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.CNE_Operations)
package body CNE_From_Quaternion is

-- ----------------------
-- --local instantiations
-- ----------------------

-- --<instantiation of a unit from "DCM_General_Operations" with CNE
-- -- specific parameters applied to the generics>---

   function Computed_CNE is new
            DCM_GEN_PKG.DCM_From_Quaternion
              (Row_Indices            => Earth_Axes,
               Col_Indices            => Navigation_Axes,
               Sin_Cos_Ratio          => Sin_Cos_Ratio,
```

```
                Direction_Cosine_Matrix => CNE_Matrices,
                Quaternion_Indices      => Quaternion_Indices,
                Quaternion_Vectors      => Quaternion_Vectors);

-- -----------------
-- --function bodies
-- -----------------

-- ---<the function to call the above function>---

   function Compute_CNE
            (quaternion : Quaternion_Vectors)
            return CNE_Matrices is
   begin
       return Computed_CNE (quaternion);
   end Compute_CNE;

end CNE_From_Quaternion;
```

3.3.2.4.9.2.9.3.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

The following table summarizes the external packages required by this part:

Name	Type	Source	Description
DCM_General_Operations	package	Direction_Cosine_Matrix_Operations	This package contains general operations for direction cosine matrices. CNE_From_Quaternion instantiates functions and procedures from this package.

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
CNE_Matrices	3X3 matrix	CNE_Operations	Type representing a direction cosine matrix indexed by the column and row types representing the navigation and earth frame.

3.3.2.4.9.2.9.3.8 LIMITATIONS

None.

3.3.2.4.9.2.9.3.9 LLCSC DESIGN

None.

3.3.2.4.9.2.9.3.10 UNIT DESIGN

None.

3.3.2.4.9.2.10 UNIT DESIGN

3.3.2.4.9.2.10.1 CNE_INITIALIZED_FROM_EARTH_POSITION UNIT DESIGN (CATALOG #P297-0)

This generic function initializes a CNE matrix from the earth position. Earth position is defined through the wander angle, latitude, and longitude.

3.3.2.4.9.2.10.1.1 REQUIREMENTS ALLOCATION

N/A

3.3.2.4.9.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.2.4.9.2.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Type	Description
Earth_Position	floating point	Type which translates into the type of lattitude and longitude.
Angles	floating point	Type which translates into the type of the wander angle.

Subprograms:

The following table describes the generic formal subroutines required by this part:

Name	Type	Description
Sin_Cos	procedure	This procedure computes the sine and cosine of an object of type Angles. The returned values are of type Sin_Cos_Ratio.
Sin_Cos	procedure	This procedure computes the sine and cosine of an object of type Earth_Position. The returned values are of type Sin_Cos_Ratio.

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
Wander_Angle	Angles	In	This object represents the wander angle which is the angle between the East axis of the navigation frame and the current missile direction of motion.
Latitude	Earth_Position	In	This object represents the current latitude of the missile's earth location.
Longitude	Earth_Position	In	This object represents the current longitude of the missile's earth location.

3.3.2.4.9.2.10.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Sin_Lat	Sin_Cos_Ratio	sine of latitude	This object stores the value of the sine of earth latitude.
Cos_Lat	Sin_Cos_Ratio	cosine of latitude	This object stores the value of the cosine of earth latitude.
Sin_Long	Sin_Cos_Ratio	sine of longitude	This object stores the value of the sine of earth longitude.
Cos_Long	Sin_Cos_Ratio	sine of longitude	This object stores the value of the cosine of earth longitude.
Sin_Wa	Sin_Cos_Ratio	sine of wander angle	This object stores the value of the sine of the wander angle.
Cos_Wa	Sin_Cos_Ratio	cosine of wander angle	This object stores the value of the cosine of the wander angle.
CNE	CNE_Matrices	N.A.	This object is a 3X3 direction cosine matrix. This object is computed and returned by this function.

3.3.2.4.9.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.2.4.9.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Direction_Cosine_Matrix_Operations.CNE_Operations)
function CNE_Initialized_From_Earth_Position
            (Wander_Angle : Angles;
             Latitude     : Earth_Position;
             Longitude    : Earth_Position)
            return CNE_Matrices is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<objects to hold the sine and cosine of latitude, longitude,
-- --  and wander angle>---

   Sin_Lat    : Sin_Cos_Ratio;
   Cos_Lat    : Sin_Cos_Ratio;
   Sin_Long   : Sin_Cos_Ratio;
   Cos_Long   : Sin_Cos_Ratio;
   Sin_Wa     : Sin_Cos_Ratio;
```

```
   Cos_Wa      : Sin_Cos_Ratio;

-- ---<the CNE to be returned>---

   CNE         : CNE_Matrices;

----------------
--begin function
----------------

begin

-- --<compute sines and cosines>--

   Sin_Cos(Latitude,     Sin_Lat,  Cos_Lat);
   Sin_Cos(Longitude,    Sin_Long, Cos_Long);
   Sin_Cos(Wander_Angle, Sin_Wa,   Cos_Wa);

-- --<compute CNE elements>--

   CNE(Greenw,East)  := -Cos_Wa * Sin_Long - Sin_Wa * Sin_Lat * Cos_Long;
   CNE(Right, East)  :=  Cos_Wa * Cos_Long - Sin_Wa * Sin_Lat * Sin_Long;
   CNE(Polar, East)  :=  Sin_Wa * Cos_Lat;

   CNE(Greenw,North) :=  Sin_Wa * Sin_Long - Cos_Wa * Sin_Lat * Cos_Long;
   CNE(Right, North) := -Sin_Wa * Cos_Long - Cos_Wa * Sin_Lat * Sin_Long;
   CNE(Polar, North) :=  Cos_Wa * Cos_Lat;

   CNE(Greenw,Up)    := Cos_Lat * Cos_Long;
   CNE(Right, Up)    := Cos_Lat * Sin_Long;
   CNE(Polar, Up)    := Sin_Lat;

   return CNE;

end CNE_Initialized_From_Earth_Position;
```

3.3.2.4.9.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.2.4.9.2.10.1.8 LIMITATIONS

None.

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3.3.2.4.10 UNIT DESIGN

None.

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```
package body Direction_Cosine_Matrix_Operations is

   package body Dcm_General_Operations is separate;

   package body Cne_Operations is separate;

end Direction_Cosine_Matrix_Operations;
```

```
separate (Direction_Cosine_Matrix_Operations)
package body Dcm_General_Operations is

   function Dcm_Initialized_From_Reference
               (Ref_Dcm_2_1    : Sin_Cos_Ratio;
                Ref_Dcm_2_2    : Sin_Cos_Ratio;
                Ref_Dcm_3_1    : Sin_Cos_Ratio;
                Ref_Dcm_3_2    : Sin_Cos_Ratio;
                Sign_Of_2_3    : INTEGER;
                Sign_Of_3_3    : INTEGER)
               return Direction_Cosine_Matrix is separate;

   package body Dcm_Trapezoidal_Integration is separate;

   procedure Perform_Rectangular_Integration_Of_Dcm
               (Dc_Matrix  : in out Direction_Cosine_Matrix;
                X_Rho      : in     Angular_Velocities;
                Y_Rho      : in     Angular_Velocities;
                Delta_Time : in     Time_Intervals) is separate;

   procedure Reorthonormalize_Dcm
               (Dcm_Matrix  : in out Direction_Cosine_Matrix) is separate;

   function Frame_Misalignment
               (Dcm_Matrix     : Direction_Cosine_Matrix;
                Ref_Dc_Matrix  : Direction_Cosine_Matrix)
               return Rotation_Angle_Vec is separate;

   function Aligned_Dcm_Matrix
               (Dcm_Matrix      : Direction_Cosine_Matrix;
                Rotation_Angle  : Rotation_Angle_Vec)
               return Direction_Cosine_Matrix is separate;

   procedure Compute_First_Row_From_Orthonormal
               (Dcm_Matrix      : in out Direction_Cosine_Matrix) is separate;

   function Dcm_From_Quaternion
               (Quaternion : Quaternion_Vectors)
               return Direction_Cosine_Matrix is separate;

end Dcm_General_Operations;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
function Dcm_Initialized_From_Reference
                  (Ref_Dcm_2_1    : Sin_Cos_Ratio;
                   Ref_Dcm_2_2    : Sin_Cos_Ratio;
                   Ref_Dcm_3_1    : Sin_Cos_Ratio;
                   Ref_Dcm_3_2    : Sin_Cos_Ratio;
                   Sign_Of_2_3    : INTEGER;
                   Sign_Of_3_3    : INTEGER)
                  return Direction_Cosine_Matrix is

-- --<direction cosine matrix to be computed>---

   Dcm_Matrix     : Direction_Cosine_Matrix;

begin

-- ---<compute new DCM>---

   if Sign_Of_2_3 = 1 then

      Dcm_Matrix(Row2,Col3) := Sqrt (1.0 - (   Ref_Dcm_2_1 *
                                               Ref_Dcm_2_1
                                           +
                                               Ref_Dcm_2_2 *
                                               Ref_Dcm_2_2   )
                                    );
   else

      Dcm_Matrix(Row2,Col3) := - Sqrt (1.0 - (   Ref_Dcm_2_1 *
                                                 Ref_Dcm_2_1
                                             +
                                                 Ref_Dcm_2_2 *
                                                 Ref_Dcm_2_2   )
                                       );
   end if;


   if Sign_Of_3_3 = 1 then
      Dcm_Matrix(Row3,Col3) := Sqrt (1.0 - (   Ref_Dcm_3_1 *
                                               Ref_Dcm_3_1
                                           +
                                               Ref_Dcm_3_2 *
                                               Ref_Dcm_3_2   )
                                    );
   else
      Dcm_Matrix(Row3,Col3) := - Sqrt (1.0 - (   Ref_Dcm_3_1 *
                                                 Ref_Dcm_3_1
                                             +
                                                 Ref_Dcm_3_2 *
                                                 Ref_Dcm_3_2   )
                                       );
   end if;

   Dcm_Matrix(Row1,Col1) :=    Ref_Dcm_2_2 *
                               Dcm_Matrix(Row3,Col3)
                           -
                               Dcm_Matrix(Row2,Col3) *
```

```
                                Ref_Dcm_3_2;

   Dcm_Matrix(Row1,Col2) :=     Dcm_Matrix(Row2,Col3) *
                                Ref_Dcm_3_1
                             -
                                Ref_Dcm_2_1 *
                                Dcm_Matrix(Row3,Col3);

   Dcm_Matrix(Row1,Col3) :=     Ref_Dcm_2_1 *
                                Ref_Dcm_3_2
                             -
                                Ref_Dcm_2_2 *
                                Ref_Dcm_3_1;

   Dcm_Matrix(Row2,Col1) := Ref_Dcm_2_1;
   Dcm_Matrix(Row2,Col2) := Ref_Dcm_2_2;
   Dcm_Matrix(Row3,Col1) := Ref_Dcm_3_1;
   Dcm_Matrix(Row3,Col2) := Ref_Dcm_3_2;

   return Dcm_Matrix;

end Dcm_Initialized_From_Reference;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
package body Dcm_Trapezoidal_Integration is

   Prev_X_Rho     : Angular_Velocities := Initial_X_Rho;
   Prev_Y_Rho     : Angular_Velocities := Initial_Y_Rho;

   procedure Reinitialize_Angular_Velocities
                  (X_Rho          : in     Angular_Velocities;
                   Y_Rho          : in     Angular_Velocities) is separate;

   procedure Perform_Trapezoidal_Integration_Of_Dcm
               (Dc_Matrix       : in out Direction_Cosine_Matrix;
                X_Rho           : in     Angular_Velocities;
                Y_Rho           : in     Angular_Velocities;
                Delta_Time      : in     Time_Intervals) is separate;

end Dcm_Trapezoidal_Integration;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations.
          Dcm_Trapezoidal_Integration)
procedure Reinitialize_Angular_Velocities
             (X_Rho           : in     Angular_Velocities;
              Y_Rho           : in     Angular_Velocities) is

begin

   Prev_X_Rho := X_Rho;
   Prev_Y_Rho := Y_Rho;

end Reinitialize_Angular_Velocities;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations.
          Dcm_Trapezoidal_Integration)
procedure Perform_Trapezoidal_Integration_Of_Dcm
             (Dc_Matrix       : in out Direction_Cosine_Matrix;
              X_Rho           : in     Angular_Velocities;
              Y_Rho           : in     Angular_Velocities;
              Delta_Time      : in     Time_Intervals) is

-- ------------------------------------------
-- ---<objects for internal calculations>---
-- ------------------------------------------

   Prev_Dcm    : Direction_Cosine_Matrix;
   X_Bound_Sum : Angular_Velocities;
   Y_Bound_Sum : Angular_Velocities;
   Del_T_Div_2 : Time_Intervals;

-----------------
--begin procedure
-----------------

begin

-- -----<copy last two rows of DCM into previous DCM before computing>-----

   Prev_Dcm(Row2,Col1) := Dc_Matrix(Row2,Col1);
   Prev_Dcm(Row2,Col2) := Dc_Matrix(Row2,Col2);
   Prev_Dcm(Row2,Col3) := Dc_Matrix(Row2,Col3);

   Prev_Dcm(Row3,Col1) := Dc_Matrix(Row3,Col1);
   Prev_Dcm(Row3,Col2) := Dc_Matrix(Row3,Col2);
   Prev_Dcm(Row3,Col3) := Dc_Matrix(Row3,Col3);

-- ---<compute sum of X and Y bounds from old and new angular velocity>---

   X_Bound_Sum := (X_Rho + Prev_X_Rho);
   Y_Bound_Sum := (Y_Rho + Prev_Y_Rho);

-- ---<compute delta time divided by 2 - for algorithm simplification>--

   Del_T_Div_2 := Delta_Time * Time_Intervals(0.5);

-- ---<compute new DCM>---

   Dc_Matrix(Row3,Col1) := Prev_Dcm(Row3,Col1) -
                           ( Y_Bound_Sum * Prev_Dcm(Row3,Col3)
                             * Del_T_Div_2);

   Dc_Matrix(Row3,Col2) := Prev_Dcm(Row3,Col2) +
                           ( X_Bound_Sum * Prev_Dcm(Row3,Col3)
                             * Del_T_Div_2);

   Dc_Matrix(Row3,Col3) := Prev_Dcm(Row3,Col3) +
                           ( Y_Bound_Sum * Prev_Dcm(Row3,Col1) -
                             X_Bound_Sum * Prev_Dcm(Row3,Col2)   )
                           * Del_T_Div_2;
```

```
   Dc_Matrix(Row2,Col1) := Prev_Dcm(Row2,Col1) -
                           ( Y_Bound_Sum * Prev_Dcm(Row2,Col3)
                             * Del_T_Div_2);

   Dc_Matrix(Row2,Col2) := Prev_Dcm(Row2,Col2) +
                           ( X_Bound_Sum * Prev_Dcm(Row2,Col3)
                             * Del_T_Div_2);

   Dc_Matrix(Row2,Col3) := Prev_Dcm(Row2,Col3) +
                           ( Y_Bound_Sum * Prev_Dcm(Row2,Col1) -
                             X_Bound_Sum * Prev_Dcm(Row2,Col2)   )
                           * Del_T_Div_2;

   Prev_X_Rho := X_Rho;
   Prev_Y_Rho := Y_Rho;

end Perform_Trapezoidal_Integration_Of_Dcm;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
procedure Perform_Rectangular_Integration_Of_Dcm
          (Dc_Matrix  : in out Direction_Cosine_Matrix;
           X_Rho      : in     Angular_Velocities;
           Y_Rho      : in     Angular_Velocities;
           Delta_Time : in     Time_Intervals) is

-- ----------------------
-- --declaration section
-- ----------------------

-- ---<DCM for computing increments (temporary) >---

   Dcm_Incr                 : Direction_Cosine_Matrix;

-- ---< objects for internal calculation >---

   Y_Rho_Times_Delta_Time : Sin_Cos_Ratio := Y_Rho * Delta_Time;
   X_Rho_Times_Delta_Time : Sin_Cos_Ratio := X_Rho * Delta_Time;

------------------
--begin procedure
------------------

begin

-- --<compute increments for bottom two rows>--

   Dcm_Incr(Row2,Col1) := -DC_Matrix(Row2,Col3) * Y_Rho_Times_Delta_Time;
   Dcm_Incr(Row2,Col2) :=  Dc_Matrix(Row2,Col3) * X_Rho_Times_Delta_Time;
   Dcm_Incr(Row2,Col3) :=  Dc_Matrix(Row2,Col1) * Y_Rho_Times_Delta_Time -
                           Dc_Matrix(Row2,Col2) * X_Rho_Times_Delta_Time;
   Dcm_Incr(Row3,Col1) := -DC_Matrix(Row3,Col3) * Y_Rho_Times_Delta_Time;
   Dcm_Incr(Row3,Col2) :=  Dc_Matrix(Row3,Col3) * X_Rho_Times_Delta_Time;
   Dcm_Incr(Row3,Col3) :=  Dc_Matrix(Row3,Col1) * Y_Rho_Times_Delta_Time -
                           Dc_Matrix(Row3,Col2) * X_Rho_Times_Delta_Time;

-- --<compute current values of bottom two Rows>--

   Dc_Matrix(Row2,Col1) := Dc_Matrix(Row2,Col1) + Dcm_Incr(Row2,Col1);
   Dc_Matrix(Row2,Col2) := Dc_Matrix(Row2,Col2) + Dcm_Incr(Row2,Col2);
   Dc_Matrix(Row2,Col3) := Dc_Matrix(Row2,Col3) + Dcm_Incr(Row2,Col3);

   Dc_Matrix(Row3,Col1) := Dc_Matrix(Row3,Col1) + Dcm_Incr(Row3,Col1);
   Dc_Matrix(Row3,Col2) := Dc_Matrix(Row3,Col2) + Dcm_Incr(Row3,Col2);
   Dc_Matrix(Row3,Col3) := Dc_Matrix(Row3,Col3) + Dcm_Incr(Row3,Col3);

end Perform_Rectangular_Integration_Of_Dcm;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
procedure Reorthonormalize_Dcm
          (Dcm_Matrix  : in out Direction_Cosine_Matrix) is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<objects for storing dot products>---

   Row2_Dot_Row2      : Real;
   Row3_Dot_Row3      : Real;
   Row2_Dot_Row3      : Real;
   Half_Row2_Dot_Row3 : Sin_Cos_Ratio;

-----------------
--begin procedure
-----------------

begin

   Row2_Dot_Row2 := Dcm_Matrix(Row2,Col1) * Dcm_Matrix(Row2,Col1) +
                    Dcm_Matrix(Row2,Col2) * Dcm_Matrix(Row2,Col2) +
                    Dcm_Matrix(Row2,Col3) * Dcm_Matrix(Row2,Col3);

   Row3_Dot_Row3 := Dcm_Matrix(Row3,Col1) * Dcm_Matrix(Row3,Col1) +
                    Dcm_Matrix(Row3,Col2) * Dcm_Matrix(Row3,Col2) +
                    Dcm_Matrix(Row3,Col3) * Dcm_Matrix(Row3,Col3);

-- -------------------------
-- --calculate column values
-- -------------------------

   Dcm_Matrix(Row2,Col1) := Dcm_Matrix(Row2,Col1) *
                            (1.5 - Real(0.5) * Row2_Dot_Row2);

   Dcm_Matrix(Row3,Col1) := Dcm_Matrix(Row3,Col1) *
                            (1.5 - Real(0.5) * Row3_Dot_Row3);

   Dcm_Matrix(Row2,Col2) := Dcm_Matrix(Row2,Col2) *
                            (1.5 - Real(0.5) * Row2_Dot_Row2);

   Dcm_Matrix(Row3,Col2) := Dcm_Matrix(Row3,Col2) *
                            (1.5 - Real(0.5) * Row3_Dot_Row3);

   Dcm_Matrix(Row2,Col3) := Dcm_Matrix(Row2,Col3) *
                            (1.5 - Real(0.5) * Row2_Dot_Row2);

   Dcm_Matrix(Row3,Col3) := Dcm_Matrix(Row3,Col3) *
                            (1.5 - Real(0.5) * Row3_Dot_Row3);

-- -------------------------
-- --<compute Rows 2 thru 3>
-- -------------------------

   Row2_Dot_Row3 := Dcm_Matrix(Row2,Col1) * Dcm_Matrix(Row3,Col1) +
```

```
                    Dcm_Matrix(Row2,Col2) * Dcm_Matrix(Row3,Col2) +
                    Dcm_Matrix(Row2,Col3) * Dcm_Matrix(Row3,Col3);

   Half_Row2_Dot_Row3 := 0.5 * Row2_Dot_Row3;

   Dcm_Matrix(Row2,Col1) := Dcm_Matrix(Row2,Col1) -
                            (Half_Row2_Dot_Row3 * Dcm_Matrix(Row3,Col1));

   Dcm_Matrix(Row3,Col1) := Dcm_Matrix(Row3,Col1) -
                            (Half_Row2_Dot_Row3 * Dcm_Matrix(Row2,Col1));

   Dcm_Matrix(Row2,Col2) := Dcm_Matrix(Row2,Col2) -
                            (Half_Row2_Dot_Row3 * Dcm_Matrix(Row3,Col2));

   Dcm_Matrix(Row3,Col2) := Dcm_Matrix(Row3,Col2) -
                            (Half_Row2_Dot_Row3 * Dcm_Matrix(Row2,Col2));

   Dcm_Matrix(Row2,Col3) := Dcm_Matrix(Row2,Col3) -
                            (Half_Row2_Dot_Row3 * Dcm_Matrix(Row3,Col3));

   Dcm_Matrix(Row3,Col3) := Dcm_Matrix(Row3,Col3) -
                            (Half_Row2_Dot_Row3 * Dcm_Matrix(Row2,Col3));

end Reorthonormalize_Dcm;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
function Frame_Misalignment
              (Dcm_Matrix     : Direction_Cosine_Matrix;
               Ref_Dc_Matrix  : Direction_Cosine_Matrix)
              return Rotation_Angle_Vec is

-- ----------------------
-- --declaration section
-- ----------------------

-- ---<the rotation angle vector that is returned>--

   Rot_Angle    : Rotation_Angle_Vec;

----------------
--begin function
----------------

begin

   Rot_Angle(X) := Dcm_Matrix(Row1,Col2) * Ref_Dc_Matrix(Row1,Col3) +
                   Dcm_Matrix(Row2,Col2) * Ref_Dc_Matrix(Row2,Col3) +
                   Dcm_Matrix(Row3,Col2) * Ref_Dc_Matrix(Row3,Col3);

   Rot_Angle(Y) := Dcm_Matrix(Row1,Col3) * Ref_Dc_Matrix(Row1,Col1) +
                   Dcm_Matrix(Row2,Col3) * Ref_Dc_Matrix(Row2,Col1) +
                   Dcm_Matrix(Row3,Col3) * Ref_Dc_Matrix(Row3,Col1);

   Rot_Angle(Z) := Dcm_Matrix(Row1,Col1) * Ref_Dc_Matrix(Row1,Col2) +
                   Dcm_Matrix(Row2,Col1) * Ref_Dc_Matrix(Row2,Col2) +
                   Dcm_Matrix(Row3,Col1) * Ref_Dc_Matrix(Row3,Col2);

   return Rot_Angle;

end Frame_Misalignment;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
function Aligned_Dcm_Matrix
         (Dcm_Matrix      : Direction_Cosine_Matrix;
          Rotation_Angle  : Rotation_Angle_Vec)
         return Direction_Cosine_Matrix is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<computed DCM to be returned>---

   Dcm_New : Direction_Cosine_Matrix;

----------------
--begin function
----------------

begin

   Dcm_New(Row2,Col1) := Dcm_Matrix(Row2,Col1) + Dcm_Matrix(Row2,Col3) *
                         Rotation_Angle(Y);

   Dcm_New(Row2,Col2) := Dcm_Matrix(Row2,Col2) - Dcm_Matrix(Row2,Col3) *
                         Rotation_Angle(X);

   Dcm_New(Row2,Col3) := Dcm_Matrix(Row2,Col3) - Dcm_Matrix(Row2,Col1) *
                         Rotation_Angle(Y) +
                         Dcm_Matrix(Row2,Col2) * Rotation_Angle(X);

   Dcm_New(Row3,Col1) := Dcm_Matrix(Row3,Col1) + Dcm_Matrix(Row3,Col3) *
                         Rotation_Angle(Y);

   Dcm_New(Row3,Col2) := Dcm_Matrix(Row3,Col2) - Dcm_Matrix(Row3,Col3) *
                         Rotation_Angle(X);

   Dcm_New(Row3,Col3) := Dcm_Matrix(Row3,Col3) - Dcm_Matrix(Row3,Col1) *
                         Rotation_Angle(Y) +
                         Dcm_Matrix(Row3,Col2) * Rotation_Angle(X);

-- ---<set first row equal to original matrix>--
-- ---<NOTE: The first row is now INVALID data>--

  Dcm_New(Row1,Col1) := Dcm_Matrix(Row1,Col1);
  Dcm_New(Row1,Col2) := Dcm_Matrix(Row1,Col2);
  Dcm_New(Row1,Col3) := Dcm_Matrix(Row1,Col3);

  return Dcm_New;

end Aligned_Dcm_Matrix;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
procedure Compute_First_Row_From_Orthonormal
            (Dcm_Matrix      : in out Direction_Cosine_Matrix) is

begin

   Dcm_Matrix(Row1,Col1) :=   Dcm_Matrix(Row2,Col2) * Dcm_Matrix(Row3,Col3)
                            - Dcm_Matrix(Row2,Col3) * Dcm_Matrix(Row3,Col2);

   Dcm_Matrix(Row1,Col2) :=   Dcm_Matrix(Row2,Col3) * Dcm_Matrix(Row3,Col1)
                            - Dcm_Matrix(Row2,Col1) * Dcm_Matrix(Row3,Col3);

   Dcm_Matrix(Row1,Col3) :=   Dcm_Matrix(Row2,Col1) * Dcm_Matrix(Row3,Col2)
                            - Dcm_Matrix(Row2,Col2) * Dcm_Matrix(Row3,Col1);

end Compute_First_Row_From_Orthonormal;
```

```
separate (Direction_Cosine_Matrix_Operations.Dcm_General_Operations)
function Dcm_From_Quaternion
            (Quaternion : Quaternion_Vectors)
            return Direction_Cosine_Matrix is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<objects to hold the squares of quaternions>---

   Q0_Sqr  : Sin_Cos_Ratio;
   Q1_Sqr  : Sin_Cos_Ratio;
   Q2_Sqr  : Sin_Cos_Ratio;
   Q3_Sqr  : Sin_Cos_Ratio;

-- ---<the DCM to be returned>---

   Dcm     : Direction_Cosine_Matrix;

-----------------
--begin function
-----------------

begin

-- -----  <compute squares of quaternions> -----

   Q0_Sqr := Quaternion(Q0) * Quaternion(Q0);
   Q1_Sqr := Quaternion(Q1) * Quaternion(Q1);
   Q2_Sqr := Quaternion(Q2) * Quaternion(Q2);
   Q3_Sqr := Quaternion(Q3) * Quaternion(Q3);


-- -----  <compute direction cosines> --------

   Dcm(Row1,Col1) := Q0_Sqr + Q1_Sqr - Q2_Sqr - Q3_Sqr;
   Dcm(Row2,Col2) := Q0_Sqr - Q1_Sqr + Q2_Sqr - Q3_Sqr;
   Dcm(Row3,Col3) := Q0_Sqr - Q1_Sqr - Q2_Sqr + Q3_Sqr;

   Dcm(Row2,Col1) := ( (Quaternion(Q0) * Quaternion(Q3))
                      +(Quaternion(Q1) * Quaternion(Q2)) )
                     * 2.0;

   Dcm(Row3,Col1) := ( (Quaternion(Q1) * Quaternion(Q3))
                      -(Quaternion(Q0) * Quaternion(Q2)) )
                     * 2.0;

   Dcm(Row1,Col2) := ( (Quaternion(Q1) * Quaternion(Q2))
                      -(Quaternion(Q0) * Quaternion(Q3)) )
                     * 2.0;

   Dcm(Row3,Col2) := ( (Quaternion(Q0) * Quaternion(Q1))
                      +(Quaternion(Q2) * Quaternion(Q3)) )
                     * 2.0;

   Dcm(Row1,Col3) := ( (Quaternion(Q0) * Quaternion(Q2))
```

```
                        +(Quaternion(Q1) * Quaternion(Q3)) )
                       * 2.0;

   Dcm(Row2,Col3) := ( (Quaternion(Q2) * Quaternion(Q3))
                        -(Quaternion(Q0) * Quaternion(Q1)) )
                       * 2.0;

   return Dcm;

end Dcm_From_Quaternion;
```

```
separate (Direction_Cosine_Matrix_Operations)
package body Cne_Operations is

   package Dcm_Gen_Pkg renames
                  Direction_Cosine_Matrix_Operations.Dcm_General_Operations;

-- ------------------------------------------------------------------
-- --<instantiation of a units from "DCM_General_Operations" with CNE
-- --  specific parameters applied to the generics>
-- ------------------------------------------------------------------

   function Initialize_From_Ref is new
               Dcm_Gen_Pkg.Dcm_Initialized_From_Reference
                  (Row_Indices            => Earth_Axes,
                   Col_Indices            => Navigation_Axes,
                   Sin_Cos_Ratio          => Sin_Cos_Ratio,
                   Direction_Cosine_Matrix => Cne_Matrices);

   procedure Reorthonormalize is new
                Dcm_Gen_Pkg.Reorthonormalize_Dcm
                   (Row_Indices            => Earth_Axes,
                    Col_Indices            => Navigation_Axes,
                    Sin_Cos_Ratio          => Sin_Cos_Ratio,
                    Direction_Cosine_Matrix => Cne_Matrices,
                    Real                   => Real);

   procedure Compute_First_Row is new
                Dcm_Gen_Pkg.Compute_First_Row_From_Orthonormal
                   (Row_Indices            => Earth_Axes,
                    Col_Indices            => Navigation_Axes,
                    Sin_Cos_Ratio          => Sin_Cos_Ratio,
                    Direction_Cosine_Matrix => Cne_Matrices);

-- ----------------
-- --separate parts
-- ----------------

   function Cne_Initialized_From_Earth_Position
                           (Wander_Angle : Angles;
                            Latitude     : Earth_Position;
                            Longitude    : Earth_Position)
                            return Cne_Matrices is separate;

   package body Cne_Integration is separate;

   package body Alignment_Parts is separate;

   package body Cne_From_Quaternion is separate;

-- ------------------------------------------------------
-- --routines acting as interfaces to instantiated routines
-- ------------------------------------------------------

   function Cne_Initialized_From_Reference
               (Ref_Cne_2_1    : Sin_Cos_Ratio;
                Ref_Cne_2_2    : Sin_Cos_Ratio;
                Ref_Cne_3_1    : Sin_Cos_Ratio;
```

```
                Ref_Cne_3_2    : Sin_Cos_Ratio;
                Sign_Of_2_3    : INTEGER;
                Sign_Of_3_3    : INTEGER)
              return Cne_Matrices is
   begin
      return Initialize_From_Ref
                (Ref_Dcm_2_1 => Ref_Cne_2_1,
                 Ref_Dcm_2_2 => Ref_Cne_2_2,
                 Ref_Dcm_3_1 => Ref_Cne_3_1,
                 Ref_Dcm_3_2 => Ref_Cne_3_2,
                 Sign_Of_2_3 => Sign_Of_2_3,
                 Sign_Of_3_3 => Sign_Of_3_3);
   end Cne_Initialized_From_Reference;

   procedure Reorthonormalize_Cne (Cne : in out Cne_Matrices) is
   begin
      Reorthonormalize (Cne);
   end Reorthonormalize_Cne;

   procedure Compute_First_Row_Of_Cne_From_Orthonormal
                (Cne : in out Cne_Matrices) is
   begin
      Compute_First_Row (Cne);
   end Compute_First_Row_Of_Cne_From_Orthonormal;

end Cne_Operations;
```

```
separate (Direction_Cosine_Matrix_Operations.Cne_Operations)
function Cne_Initialized_From_Earth_Position
            (Wander_Angle : Angles;
             Latitude     : Earth_Position;
             Longitude    : Earth_Position)
            return Cne_Matrices is

-- ---------------------
-- --declaration section
-- ---------------------

-- ---<objects to hold the sine and cosine of latitude, longitude,
-- --   and wander angle>---

   Sin_Lat    : Sin_Cos_Ratio;
   Cos_Lat    : Sin_Cos_Ratio;
   Sin_Long   : Sin_Cos_Ratio;
   Cos_Long   : Sin_Cos_Ratio;
   Sin_Wa     : Sin_Cos_Ratio;
   Cos_Wa     : Sin_Cos_Ratio;

-- ---<the CNE to be returned>---

   Cne        : Cne_Matrices;

----------------
--begin function
----------------

begin

-- --<compute sines and cosines>--

   Sin_Cos(Latitude,     Sin_Lat,  Cos_Lat);
   Sin_Cos(Longitude,    Sin_Long, Cos_Long);
   Sin_Cos(Wander_Angle, Sin_Wa,   Cos_Wa);

-- --<compute CNE elements>--

   Cne(Greenw,East)  := -COs_Wa * Sin_Long - Sin_Wa * Sin_Lat * Cos_Long;
   Cne(Right, East)  :=  Cos_Wa * Cos_Long - Sin_Wa * Sin_Lat * Sin_Long;
   Cne(Polar, East)  :=  Sin_Wa * Cos_Lat;

   Cne(Greenw,North) :=  Sin_Wa * Sin_Long - Cos_Wa * Sin_Lat * Cos_Long;
   Cne(Right, North) := -SIn_Wa * Cos_Long - Cos_Wa * Sin_Lat * Sin_Long;
   Cne(Polar, North) :=  Cos_Wa * Cos_Lat;

   Cne(Greenw,Up)    := Cos_Lat * Cos_Long;
   Cne(Right, Up)    := Cos_Lat * Sin_Long;
   Cne(Polar, Up)    := Sin_Lat;

   return Cne;

end Cne_Initialized_From_Earth_Position;
```

```
separate (Direction_Cosine_Matrix_Operations.Cne_Operations)
package body Cne_Integration is

-- ----------------------
-- --local instantiations
-- ----------------------

-- --<instantiation of a units from "DCM_General_Operations" with CNE
-- --  specific parameters applied to the generics>---

   package Integrate_Trap is new
             Dcm_Gen_Pkg.Dcm_Trapezoidal_Integration
               (Angular_Velocities      => Angular_Velocities,
                Time_Intervals          => Time_Intervals,
                Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => Cne_Matrices,
                Initial_X_Rho           => Initial_East_Rho,
                Initial_Y_Rho           => Initial_North_Rho);

   procedure Integrate_Rect is new
             Dcm_Gen_Pkg.Perform_Rectangular_Integration_Of_Dcm
               (Angular_Velocities      => Angular_Velocities,
                Time_Intervals          => Time_Intervals,
                Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => Cne_Matrices);

-- ------------------------------------------------------
-- --routines acting as interfaces to instantiated routines
-- ------------------------------------------------------

-- --------[Trapezoidal Integration]---------

   procedure Perform_Trapezoidal_Integration_Of_Cne
               (Cne            : in out Cne_Matrices;
                East_Rho       : in     Angular_Velocities;
                North_Rho      : in     Angular_Velocities;
                Delta_Time     : in     Time_Intervals) is
   begin
      Integrate_Trap.Perform_Trapezoidal_Integration_Of_Dcm
                           (Cne, East_Rho, North_Rho, Delta_Time);
   end Perform_Trapezoidal_Integration_Of_Cne;


   procedure Reinit_Ang_Vel_For_Trapez_Integ_Of_Cne
               (East_Rho     : in     Angular_Velocities;
                North_Rho    : in     Angular_Velocities) is
   begin
      Integrate_Trap.Reinitialize_Angular_Velocities
                           (East_Rho, North_Rho);
   end Reinit_Ang_Vel_For_Trapez_Integ_Of_Cne;


-- --------[Rectangular Integration]---------
```

```
   procedure Perform_Rectangular_Integration_Of_Cne
             (Cne        : in out Cne_Matrices;
              East_Rho   : in     Angular_Velocities;
              North_Rho  : in     Angular_Velocities;
              Delta_Time : in     Time_Intervals) is
   begin
      Integrate_Rect (Cne, East_Rho, North_Rho, Delta_Time);
   end Perform_Rectangular_Integration_Of_Cne;


end Cne_Integration;
```

```
separate (Direction_Cosine_Matrix_Operations.Cne_Operations)
package body Alignment_Parts is

-- ----------------------
-- --local instantiations
-- ----------------------

--- <instantiation of a unit from "DCM_General_Operations" with CNE
--   specific parameters applied to the generics>---

   function Computed_Frame_Misalignment is new
            Dcm_Gen_Pkg.Frame_Misalignment
               (Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => Cne_Matrices,
                Rotation_Indices        => Rotation_Indices,
                Rotation_Angles         => Rotation_Angles,
                Rotation_Angle_Vec      => Rotation_Angle_Vec);

   function Align_Cne_Matrix is new
             Dcm_Gen_Pkg.Aligned_Dcm_Matrix
               (Row_Indices             => Earth_Axes,
                Col_Indices             => Navigation_Axes,
                Sin_Cos_Ratio           => Sin_Cos_Ratio,
                Direction_Cosine_Matrix => Cne_Matrices,
                Rotation_Indices        => Rotation_Indices,
                Rotation_Angles         => Rotation_Angles,
                Rotation_Angle_Vec      => Rotation_Angle_Vec);

-- ------------------------------------------------------------
-- --routines acting as interfaces to instantiated routines
-- ------------------------------------------------------------

-- --------[Frame Misalignment]----------

   function Frame_Misalignment_Of_Cne
               (Cne            : Cne_Matrices;
                Ref_Dc_Matrix  : Cne_Matrices)
               return Rotation_Angle_Vec is
   begin
      return Computed_Frame_Misalignment (Cne, Ref_Dc_Matrix);
   end Frame_Misalignment_Of_Cne;

-- --------[Align CNE Matrix]----------

   function Aligned_Cne_Matrix
               (Cne             : Cne_Matrices;
                Rotation_Angle  : Rotation_Angle_Vec)
               return Cne_Matrices is
   begin
      return Align_Cne_Matrix (Cne, Rotation_Angle);
   end Aligned_Cne_Matrix;

end Alignment_Parts;
```

```
separate (Direction_Cosine_Matrix_Operations.Cne_Operations)
package body Cne_From_Quaternion is

-- ----------------------
-- --local instantiations
-- ----------------------

-- --<instantiation of a unit from "DCM_General_Operations" with CNE
-- --  specific parameters applied to the generics>---

   function Computed_Cne is new
            Dcm_Gen_Pkg.Dcm_From_Quaternion
              (Row_Indices             => Earth_Axes,
               Col_Indices             => Navigation_Axes,
               Sin_Cos_Ratio           => Sin_Cos_Ratio,
               Direction_Cosine_Matrix => Cne_Matrices,
               Quaternion_Indices      => Quaternion_Indices,
               Quaternion_Vectors      => Quaternion_Vectors);

-- -----------------
-- --function bodies
-- -----------------

-- ---<the function to call the above function>---

   function Compute_Cne
            (Quaternion : Quaternion_Vectors)
            return Cne_Matrices is
   begin
       return Computed_Cne (Quaternion);
   end Compute_Cne;

end Cne_From_Quaternion;
```

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3.3.3 KALMAN FILTER

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3.3.3.1 KALMAN FILTER COMMON PARTS (BODY) TLCSC 651 (CATALOG #P163-0)

This part, which is designed as an Ada package, contains specifications for all CAMP parts which can be used to implement a Kalman Filter regardless of the type of H matrix used.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.1.1 REQUIREMENTS ALLOCATION

The following chart summarizes the allocation of CAMP requirements to this

Tlcsc:

Name	Requirements Allocation
State_Transition_And_Process_Noise_Matrices_ Manager	R145
Error_Covariance_Matrix_Manager	R146
State_Transition_Matrix_Manger	R148

3.3.3.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.3 INPUT/OUTPUT

None.

3.3.3.1.4 LOCAL DATA

None.

3.3.3.1.5 PROCESS CONTROL

Not applicable.

3.3.3.1.6 PROCESSING

The following describes the processing performed by this part:

```
package body Kalman_Filter_Common_Parts is

   package body State_Transition_And_Process_Noise_Matrices_Manager is separate;

   package body Error_Covariance_Matrix_Manager                     is separate;

   package body State_Transition_Matrix_Manager                     is separate;
```

```
end Kalman_Filter_Common_Parts;
```

3.3.3.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.1.8 LIMITATIONS

None.

3.3.3.1.9 LLCSC DESIGN

3.3.3.1.9.1 STATE_TRANSITION_AND_PROCESS_NOISE_MATRICES_MANAGER PACKAGE DESIGN (CATALOG #P164-0)

This LLCSC is a generic package which manages the State Transition (Phi) and Process Noise (Q) matrices. It consists of an Initialize procedure, a Propagation function, and functions which return the stored value of each of the two matrices.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.1.9.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R145.

3.3.3.1.9.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Base Type	Description
Time_Intervals	floating point	Type for the delta time variable
Phi_Matrices	private	Data type of N x N Phi Matrix
Integrated_F_ Matrices	private	Data type of N x N Matrix for F integration
Integrated_Q_ Matrices	private	Data type of N x N Matrix for Q integration
Q_Matrices	private	Data type of N x N Q Matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Add_To_Identity	procedure	Adds the identity matrix to a Integrated_F_Matrices
Set_To_Identity_Matrix	function	Sets a Phi_Matrices type matrix to the identity matrix
Set_To_Zero_Matrix	function	Sets a Q_Matrices type matrix to the zer matrix
ABA_Transpose	function	Multiplies a Integrated_F_Matrices type matrix by the transpose of a Q_Matrices type matrix yielding a Q_Matrices type matrix
"*"	function	Multiplies a Integrated F Matrix by a Time_Interval yielding a Integrated Q Matrix
"*"	function	Multiplies a Integrated F Matrix by a Phi Matrix yielding a Phi Matrix
"+"	function	Adds a Integrated Q Matrix to a Q Marix yielding a Q Matrix

3.3.3.1.9.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Prop_Phi	Statically_Sparse_Matrices	variable	The propagated state transition matrix
Prop_Q	Symmetric Matrices	variable	The propagated process noise matrix

3.3.3.1.9.1.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Common_Parts)
package body State_Transition_And_Process_Noise_Matrices_Manager is

   Prop_Phi : Phi_Matrices;
   Prop_Q   : Q_Matrices;

end State_Transition_And_Process_Noise_Matrices_Manager;
```

3.3.3.1.9.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.1.9.1.8 LIMITATIONS

None.

3.3.3.1.9.1.9 LLCSC DESIGN

None.

3.3.3.1.9.1.10 UNIT DESIGN

3.3.3.1.9.1.10.1 INITIALIZE UNIT DESIGN

This unit initializes the Propagated Phi matrix to the identity, and the Propagated Q matrix to the zero matrix.

3.3.3.1.9.1.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R145

3.3.3.1.9.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.1.10.1.3 INPUT/OUTPUT

None.

3.3.3.1.9.1.10.1.4 LOCAL DATA

None.

3.3.3.1.9.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Initialize is

begin

   Set_To_Identity_Matrix (Source => Prop_Phi);

   Set_To_Zero_Matrix (Source => Prop_Q);

end Initialize;
```

3.3.3.1.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
Phi_Matrices	private	Data type of matrix used to represent Phi matrices
Q_Matrices	private	Data type of matrix used to represent Q matrices

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Phi_Matrices	variable	The propagated state transition matrix
Prop_Q	Q_Matrices	variable	The propagated process noise matrix

3.3.3.1.9.1.10.1.8 LIMITATIONS

None.

3.3.3.1.9.1.10.2 PROPAGATE UNIT DESIGN

This unit propagates new Propagated Phi and Propagated Q matrices given a new Integrated System Description Matrix and Time Interval

3.3.3.1.9.1.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R145.

3.3.3.1.9.1.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.1.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
Integrated_F	Integrated_F_Matrices	in	Current value for the System Description matrix already integrated across time
Q	Integrated_Q_Matrices	in	Current process noise matrix
DT	Time_Intervals	in	Time since the last propagation

3.3.3.1.9.1.10.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Phi	Integrated_F_Matrices	variable	Computed process noise matrix matrix

3.3.3.1.9.1.10.2.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.1.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
   procedure Propagate (Integrated_F : in Integrated_F_Matrices;
                        Q            : in Integrated_Q_Matrices;
                        DT           : in Time_Intervals) is

      Phi      : Integrated_F_Matrices;

   begin

--    -- Propagate Phi

      Phi := Add_To_Identity (Source_Matrix => Integrated_F);

      Prop_Phi := Phi * Prop_Phi;

--    -- Propagate Q

      Prop_Q := Q * DT + ABA_Transpose( Phi, Prop_Q ) ;

   end Propagate;
```

3.3.3.1.9.1.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Base Type	Description
Time_Intervals	floating point type	Type for the delta time variable
Phi_Matrices	private	Data type of N x N Phi Matrix
Integrated_F_Matrices	private	Data type of N x N Matrix for F integration
Integrated_Q_Matrices	private	Data type of N x N Matrix for Q integration
Q_Matrices	private	Data type of N x N Q Matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Phi_Matrices	variable	The propagated state transition matrix
Prop_Q	Q_Matrices	variable	The propagated process noise matrix

3.3.3.1.9.1.10.2.8 LIMITATIONS

None.

3.3.3.1.9.1.10.3 GET_CURRENT UNIT DESIGN

This unit returns the current value of the Propagated Phi and Propagated Q matrices.

3.3.3.1.9.1.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R145.

3.3.3.1.9.1.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.1.10.3.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
Propagated_Phi	Phi_Matrices	out	Stored Propagated State Transition matrix
Propagated_Q	Q_Matrices	out	Stored Propagated Process Noise Matrix

3.3.3.1.9.1.10.3.4 LOCAL DATA

None.

3.3.3.1.9.1.10.3.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.1.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Get_Current (Propagated_Phi : out Phi_Matrices;
                       Propagated_Q   : out Q_Matrices ) is

begin

   Propagated_Phi := Prop_Phi;

   Propagated_Q   := Prop_Q;

end Get_Current;
```

3.3.3.1.9.1.10.3.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
Phi_Matrices	private	Data type of N x N Phi Matrix
Q_Matrices	private	Data type of N x N Q Matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Phi_Matrices	variable	The propagated state transition matrix
Prop_Q	Q_Matrices	variable	The propagated process noise matrix

3.3.3.1.9.1.10.3.8 LIMITATIONS

None.

3.3.3.1.9.1.10.4 PROPAGATED_PHI UNIT DESIGN

This unit returns the current value of the Propagated Phi matrix

3.3.3.1.9.1.10.4.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R145.

3.3.3.1.9.1.10.4.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.1.10.4.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
<returned value>	Phi_Matrices	out	Stored Propagated State Transition matrix

3.3.3.1.9.1.10.4.4 LOCAL DATA

None.

3.3.3.1.9.1.10.4.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.1.10.4.6 PROCESSING

The following describes the processing performed by this part:

```
function Propagated_Phi return Phi_Matrices is

begin

   return Prop_Phi;

end Propagated_Phi;
```

3.3.3.1.9.1.10.4.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
Phi_Matrices	private	Data type for N x N phi matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Phi_Matrices	variable	The propagated state transition matrix

3.3.3.1.9.1.10.4.8 LIMITATIONS

None.

3.3.3.1.9.2 ERROR_COVARIANCE_MATRIX_MANAGER PACKAGE DESIGN (CATALOG #P165-0)

This LLCSC is a generic package which manages the Error Covariance Matrix; it consists of an Initialize procedure, a Propagation procedure, and a P function, which returns the current Error Covariance matrix value

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.1.9.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R146.

3.3.3.1.9.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Base Type	Description
Phi_Matrices	private	Data type of N x N Phi matrix
P_And_Q_Matrices	private	Data type of N x N P and Q matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
ABA_Transpose	function	Multiplies a Phi matrix by the by the transpose of a P and Q matrix yielding a P and Q matrix
"+"	function	Adds two P and Q matrices yielding a P and Q matrix

3.3.3.1.9.2.4 LOCAL DATA

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Stored_P	P_And_Q_Matrices	variable	The propagated error covariance matrix which is stored by part

3.3.3.1.9.2.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Common_Parts)
package body Error_Covariance_Matrix_Manager is
   Stored_P : P_And_Q_Matrices;
end Error_Covariance_Matrix_Manager;
```

3.3.3.1.9.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.1.9.2.8 LIMITATIONS

None.

3.3.3.1.9.2.9 LLCSC DESIGN

None.

3.3.3.1.9.2.10 UNIT DESIGN

3.3.3.1.9.2.10.1 INITIALIZE UNIT DESIGN

This unit initializes the Error Covariance matrix to the matrix sent in.

3.3.3.1.9.2.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R146

3.3.3.1.9.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.2.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
Initial_P	P_And_Q_ Matrices	in	This is the value to which the Error Covariance Matrix will be initialized

3.3.3.1.9.2.10.1.4 LOCAL DATA

None.

3.3.3.1.9.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Initialize (Initial_P : in P_And_Q_Matrices) is

begin

   Stored_P := Initial_P;

end Initialize;
```

3.3.3.1.9.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
P_And_Q_Matrices	private	Data type of N x N P and Q matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Stored_P	P_And_Q_ Matrices	variable	The propagated error covariance matrix which is stored by part

3.3.3.1.9.2.10.1.8 LIMITATIONS

None.

3.3.3.1.9.2.10.2 PROPAGATE UNIT DESIGN

This unit propagates the Error Covariance Matrix given the Propagated Phi and Propagated Q matrices

3.3.3.1.9.2.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R146.

3.3.3.1.9.2.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.2.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
Propagated_Phi	Phi_Matrices	in	Current value for the Propagated State Transition Matrix
Propagated_Q	P_And_Q_ Matrices	in	Current value for the Propagated Process Noise Matrix

3.3.3.1.9.2.10.2.4 LOCAL DATA

None.

3.3.3.1.9.2.10.2.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.2.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Propagate  (Propagated_Phi : in Phi_Matrices;
                      Propagated_Q   : in P_And_Q_Matrices) is

begin

   Stored_P := ABA_Transpose( Propagated_Phi, Stored_P ) + Propagated_Q;

end Propagate;
```

3.3.3.1.9.2.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
Phi_Matrices	private	Data type of n x n Phi matrix
P_And_Q_Matrices	private	Data type of n x n P and Q matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Stored_P	P_And_Q_ Matrices	variable	The propagated error covariance matrix which is stored by part

3.3.3.1.9.2.10.2.8 LIMITATIONS

None.

3.3.3.1.9.2.10.3 P UNIT DESIGN

This unit returns the current value of the P matrix

3.3.3.1.9.2.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R146.

3.3.3.1.9.2.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.2.10.3.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
<returned value>	P_And_Q_ Matrices	out	Stored Propagated Error Covariance matrix

3.3.3.1.9.2.10.3.4 LOCAL DATA

None.

3.3.3.1.9.2.10.3.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.2.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
function P return P_And_Q_Matrices is
begin
   return Stored_P;
end P;
```

3.3.3.1.9.2.10.3.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
P_and_Q_Matrices	private	Data type of n x n P and Q matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Stored_P	P_and_Q_ Matrices	variable	The current propagated error covariance matrix

3.3.3.1.9.2.10.3.8 LIMITATIONS

None.

3.3.3.1.9.3 STATE_TRANSITION_MATRIX_MANAGER PACKAGE DESIGN (CATALOG #P166-0)

This LLCSC is a generic package which manages the State Transition Matrix, commonly known as the Phi matrix. It consists of an Initialization procedure, a Propagation function, and a function which returns the stored Propagated_Phi value.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.1.9.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R148.

3.3.3.1.9.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal types required by this part:

Name	Base Type	Description
Integrated_F_Matrices	private	Data type for n x n F integration matrix
Phi_Matrices	private	Data type for n x n Phi matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Set_To_Identity_	function	Sets a Phi matrix to the Identity
"*"	function	Multiplies an Integrated F matrix by Phi matrix yielding a Phi matrix

3.3.3.1.9.3.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Prop_Phi	Phi_Matrices	variable	The propagated state transition matrix

3.3.3.1.9.3.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.3.6 PROCESSING

The following describes the processing performed by this part:

separate (Kalman_Filter_Common_Parts)

```
package body State_Transition_Matrix_Manager is

   Prop_Phi : Phi_Matrices;

end State_Transition_Matrix_Manager;
```

3.3.3.1.9.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.1.9.3.8 LIMITATIONS

None.

3.3.3.1.9.3.9 LLCSC DESIGN

None.

3.3.3.1.9.3.10 UNIT DESIGN

3.3.3.1.9.3.10.1 INITIALIZE UNIT DESIGN

This unit initializes the Propagated Phi matrix to the identity.

3.3.3.1.9.3.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R148

3.3.3.1.9.3.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.3.10.1.3 INPUT/OUTPUT

None.

3.3.3.1.9.3.10.1.4 LOCAL DATA

None.

3.3.3.1.9.3.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.3.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Initialize is

begin

   Set_To_Identity_Matrix (Matrix => Prop_Phi);

end Initialize;
```

3.3.3.1.9.3.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the data types defined by the parent component:

Name	Base Type	Description
Phi_Matrices	private	Data type for n x n Phi matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Integrated_F_Matrix	variable	The propagated state transition matrix

3.3.3.1.9.3.10.1.8 LIMITATIONS

None.

3.3.3.1.9.3.10.2 PROPAGATE UNIT DESIGN

This unit propagates a new Propagated Phi matrix.

3.3.3.1.9.3.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R148.

3.3.3.1.9.3.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.3.10.2.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
Phi	Integrated_F_Matrices	in	Current value for the State Transition Matrix

3.3.3.1.9.3.10.2.4 LOCAL DATA

None.

3.3.3.1.9.3.10.2.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.3.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Propagate (Integrated_F : in Integrated_F_Matrices) is
begin
   Prop_Phi := Integrated_F * Prop_Phi;
end Propagate;
```

3.3.3.1.9.3.10.2.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
Integrated_F_ Matrices	private	Data type for N by N matrix for F Integration
Phi_Matrices	private	Data Type for N by N Phi matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Integrated_F_Matrices	variable	The propagated state transition matrix

3.3.3.1.9.3.10.2.8 LIMITATIONS

None.

3.3.3.1.9.3.10.3 PROPAGATED_PHI UNIT DESIGN

This unit returns the current value of the Propagated Phi matrix

3.3.3.1.9.3.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R148.

3.3.3.1.9.3.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.1.9.3.10.3.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this unit's formal parameters:

Name	Type	Mode	Description
<returned value>	Phi_Matrices	out	Stored Propagated State Transition matrix

3.3.3.1.9.3.10.3.4 LOCAL DATA

None.

3.3.3.1.9.3.10.3.5 PROCESS CONTROL

Not applicable.

3.3.3.1.9.3.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
function Propagated_Phi return Phi_Matrices is

begin

   return Prop_Phi;

end Propagated_Phi;
```

3.3.3.1.9.3.10.3.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Data types:

The following table summarizes the types required by this part and defined in the parent component:

Name	Base Type	Description
Phi_Matrices	private	Data type for n x n Phi matrix

Data objects:

The following table summarizes the objects required by this part and defined in the parent component:

Name	Type	Value	Description
Prop_Phi	Phi_Matrices	variable	The propagated state transition matrix

3.3.3.1.9.3.10.3.8 LIMITATIONS

None.

3.3.3.1.10 UNIT DESIGN

None.

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```
package body Kalman_Filter_Common_Parts is

   package body State_Transition_And_Process_Noise_Matrices_Manager is separate;

   package body Error_Covariance_Matrix_Manager                     is separate;

   package body State_Transition_Matrix_Manager                     is separate;

end Kalman_Filter_Common_Parts;
```

```
separate (Kalman_Filter_Common_Parts)
package body State_Transition_And_Process_Noise_Matrices_Manager is

   Prop_Phi : Phi_Matrices;
   Prop_Q   : Q_Matrices;

pragma PAGE;
   procedure Initialize is

   begin

      Set_To_Identity_Matrix (Source => Prop_Phi);

      Set_To_Zero_Matrix (Source => Prop_Q);

   end Initialize;

pragma PAGE;
   procedure Propagate (Integrated_F : in Integrated_F_Matrices;
                        Q            : in Integrated_Q_Matrices;
                        Dt           : in Time_Intervals) is

      Phi      : Integrated_F_Matrices;

   begin


--       -- Propagate Phi

      Phi := Add_To_Identity (Source_Matrix => Integrated_F);

      Prop_Phi := Phi * Prop_Phi;


--       -- Propagate Q

      Prop_Q := Q * Dt + Aba_Transpose( Phi, Prop_Q ) ;

   end Propagate;

pragma PAGE;
   procedure Get_Current (Propagated_Phi : out Phi_Matrices;
                          Propagated_Q   : out Q_Matrices ) is

   begin

      Propagated_Phi := Prop_Phi;

      Propagated_Q   := Prop_Q;

   end Get_Current;

pragma PAGE;
   function Propagated_Phi return Phi_Matrices is

   begin
```

```
        return Prop_Phi;
    end Propagated_Phi;
end State_Transition_And_Process_Noise_Matrices_Manager;
```

```
separate (Kalman_Filter_Common_Parts)

package body Error_Covariance_Matrix_Manager is

   Stored_P : P_And_Q_Matrices;

pragma PAGE;
   procedure Initialize (Initial_P : in P_And_Q_Matrices) is

   begin

      Stored_P := Initial_P;

   end Initialize;

pragma PAGE;
   procedure Propagate  (Propagated_Phi : in Phi_Matrices;
                         Propagated_Q   : in P_And_Q_Matrices) is

   begin

      Stored_P := Aba_Transpose( Propagated_Phi, Stored_P ) + Propagated_Q;

   end Propagate;

pragma PAGE;
   function P return P_And_Q_Matrices is

   begin

      return Stored_P;

   end P;

end Error_Covariance_Matrix_Manager;
```

```
separate (Kalman_Filter_Common_Parts)

package body State_Transition_Matrix_Manager is

   Prop_Phi : Phi_Matrices;

pragma PAGE;
   procedure Initialize is

   begin

      Set_To_Identity_Matrix (Matrix => Prop_Phi);

   end Initialize;

pragma PAGE;
   procedure Propagate (Integrated_F : in Integrated_F_Matrices) is

   begin

      Prop_Phi := Integrated_F * Prop_Phi;

   end Propagate;

pragma PAGE;
   function Propagated_Phi return Phi_Matrices is

   begin

      return Prop_Phi;

   end Propagated_Phi;

end State_Transition_Matrix_Manager;
```

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3.3.3.2 KALMAN FILTER COMPACT H PARTS (BODY) TLCSC (CATALOG #P137-0)

This part, which is designed as an Ada package, contains bodies for all CAMP parts which can be used to implement a Kalman Filter when a compact Measurement Sensitivity Matrix (Compact H Matrix) is used

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.2.1 REQUIREMENTS ALLOCATION

The following chart summarizes the allocation of CAMP requirements to this

Tlcsc:

Name	Requirements Allocation
Kalman_Update	R147
Compute_Kalman_Gain	R149
Update_Error_Covariance_Matrix	R150
Update_State_Vector	R151
Sequentially_Update_Covariance_Matrix_and_ State_Vector	R152

3.3.3.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.3 INPUT/OUTPUT

None.

3.3.3.2.4 LOCAL DATA

None.

3.3.3.2.5 PROCESS CONTROL

Not applicable.

3.3.3.2.6 PROCESSING

The following describes the processing performed by this part:

```
package body Kalman_Filter_Compact_H_Parts is

   function Compute_Kalman_Gain
               (P                    : P_Matrices;
                Measurement_Number   : Measurement_Indices;
```

```
                Compact_H           : Compact_H_Matrices;
                Measurement_Variance : Measurement_Variance_Vectors)
            return K_Column_Vectors is separate;

   procedure Update_Error_Covariance_Matrix
               (P                  : in out P_Matrices;
                Measurement_Number : in     Measurement_Indices;
                K                  : in     K_Column_Vectors;
                Compact_H          : in     Compact_H_Matrices)
               is separate;

   procedure Update_State_Vector
               (X                  : in out State_Vectors;
                Z                  : in     Measurement_Vectors;
                K                  : in     K_Column_Vectors;
                Measurement_Number : in     Measurement_Indices;
                Compact_H          : in     Compact_H_Matrices)
               is separate;

   package body Sequentially_Update_Covariance_Matrix_and_State_Vector
                  is separate;

   package body Kalman_Update is separate;

   procedure Update_Error_Covariance_Matrix_General_Form
               (P                  : in out P_Matrices;
                Measurement_Number : in     Measurement_Indices;
                K                  : in     K_Column_Vectors;
                Compact_H          : in     Compact_H_Matrices;
                Measurement_Variance : in   Measurement_Variance_Vectors)
            is separate;

end Kalman_Filter_Compact_H_Parts;
```

3.3.3.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.2.8 LIMITATIONS

None.

3.3.3.2.9 LLCSC DESIGN

3.3.3.2.9.1 SEQUENTIALLY UPDATE COVARIANCE MATRIX AND STATE VECTOR PACKAGE DESIGN (CATALOG #P141-0)

This LLCSC is a generic package which contains one procedure, "Update", which updates the Covariance Matrix, P, and state Vector, X.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.2.9.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R152.

3.3.3.2.9.1.2 LOCAL ENTITIES DESIGN

Packages:

As described above, this package body instantiates Part R149, Compute Kalman Gain, part R150, Update Error Covariance Matrix, and part R151, Update State Vector

3.3.3.2.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal data types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements making up the Kalman Filter aggregates
P_Matrices	private	Data type of P matrix
Measurement_Variance_Vectors	vector	Vector indexed by Measurement Indices containing Kalman_Filter_Elements
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
P_Row_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices	vector	Data type of Compact H matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Element	function	Extracts an element of a P Matrix
Row	function	Extracts a row of a P matrix
"*"	function	A K Column Vector is multiplied by the transpose of a P Row vector, yielding a P matrix
"-"	function	Two P matrices are added, yielding a Symmetric matrix
"+"	function	Add a state vector and a K column vector, yielding a state vector
"*"	function	Multiply a K column vector by a Kalman Filter Element, yielding a K column vector

3.3.3.2.9.1.4 LOCAL DATA

None.

3.3.3.2.9.1.5 PROCESS CONTROL

Not applicable.

3.3.3.2.9.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Compact_H_Parts)
package body Sequentially_Update_Covariance_Matrix_and_State_Vector is

   K : K_Column_Vectors;


   function Compute_K is new Compute_Kalman_Gain
               (State_Indices           => State_Indices,
                Measurement_Indices     => Measurement_Indices,
                Kalman_Filter_Elements  => Kalman_Filter_Elements,
                P_Matrices              => P_Matrices,
                Measurement_Variance_Vectors
                                        => Measurement_Variance_Vectors,
                K_Column_Vectors        => K_Column_Vectors,
                Compact_H_Matrices      => Compact_H_Matrices);
```

```
   procedure Update_P is new Update_Error_Covariance_Matrix
             (State_Indices           => State_Indices,
              Measurement_Indices     => Measurement_Indices,
              Kalman_Filter_Elements  => Kalman_Filter_Elements,
              P_Matrices              => P_Matrices,
              P_Row_Vectors           => P_Row_Vectors,
              K_Column_Vectors        => K_Column_Vectors,
              Compact_H_Matrices      => Compact_H_Matrices);


   procedure Update_X is new Update_State_Vector
             (State_Indices           => State_Indices,
              Measurement_Indices     => Measurement_Indices,
              Kalman_Filter_Elements  => Kalman_Filter_Elements,
              Measurement_Vectors     => Measurement_Vectors,
              K_Column_Vectors        => K_Column_Vectors,
              State_Vectors           => State_Vectors,
              Compact_H_Matrices      => Compact_H_Matrices);

end Sequentially_Update_Covariance_Matrix_and_State_Vector;
```

3.3.3.2.9.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Compute_Kalman_Gain	generic function	Kalman_Filter_Common	Computes the Kalman Gain Vector, K
Update_State_Vector	generic procedure	Kalman_Filter_Common	Updates the State Vector, X
Update_Error_Covariance_Matrix	generic procedure	Kalman_Filter_Common	Updates the Error Covariance Matrix, P

3.3.3.2.9.1.8 LIMITATIONS

None.

3.3.3.2.9.1.9 LLCSC DESIGN

None.

3.3.3.2.9.1.10 UNIT DESIGN

3.3.3.2.9.1.10.1 UPDATE UNIT DESIGN

This unit is a procedure which does the update of the Covariance Matrix, P, and the State_Vector, X.

3.3.3.2.9.1.10.1.1 REQUIREMENTS ALLOCATION

This parts meets CAMP Requirement R152.

3.3.3.2.9.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.9.1.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
P	P_Matrices	in/out	Error Covariance Matrix (P) to be updated
X	State_Vectors	in/out	State Vector (X), to be updatd
Z	Measurement_ Vectors	in	Current Measurement Vector(Z)
Compact_H	Compact_H_ Matrices	in	Current Measurement Sensitivity Array (Compact H)
Measurement_ Variance	Measurement_ Variance_Vectors	in	Current Measurement Variance Array

3.3.3.2.9.1.10.1.4 LOCAL DATA

None.

3.3.3.2.9.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.2.9.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
procedure Update
                (P                    : in out P_Matrices;
                 X                    : in out State_Vectors;
                 Z                    : in     Measurement_Vectors;
                 Compact_H            : in     Compact_H_Matrices;
                 Measurement_Variance : in     Measurement_Variance_Vectors) is

begin

   for Measurement_Number in Measurement_Indices loop

      K := Compute_K (P                    => P,
                      Measurement_Number   => Measurement_Number,
                      Compact_H            => Compact_H,
                      Measurement_Variance => Measurement_Variance);

      Update_P (P                  => P,
                Measurement_Number => Measurement_Number,
                K                  => K,
                Compact_H          => Compact_H);

      Update_X (X                  => X,
                Z                  => Z,
                K                  => K,
                Measurement_Number => Measurement_Number,
                Compact_H          => Compact_H);

   end loop;

end Update;
```

3.3.3.2.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Compute_Kalman_Gain	generic function	parent	Computes the Kalman Gain Vector, K
Update_State_Vector	generic procedure	parent	Updates the State Vector, X
Update_Error_Covariance_Matrix	generic procedure	parent	Updates the Error Covariance Matrix, P

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Base Type	Description
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
P_Matrices	private	Data type of P matrix
Measurement_Variance_Vectors	vector	Vector indexed by Measurement Indices containing Kalman_Filter_Elements
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices	vector	Data type of Compact H matrix

Data objects:

The following table summarizes the objects required by this part and defined elsewhere in the parent top level component:

Name	Type	Value	Description
K	K_Column_Vectors	variable	Stores the value of the Kalman Gain Vector (K)

3.3.3.2.9.1.10.1.8 LIMITATIONS

None.

3.3.3.2.9.2 KALMAN_UPDATE (BODY) PACKAGE DESIGN (CATALOG #P142-0)

This LLCSC is a generic package body which contains 1 procedure, "Update" which updates the State Vector, X, given the old X vector, the Z vector, the K vector, the Measurement Number, and the Compact H array.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.2.9.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R147.

3.3.3.2.9.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal data types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements making up the Kalman Filter aggregates
Phi_Matrices	private	Data type of Phi matrix
P_And_Q_Matrices	private	Data type of a P and Q matrix
Measurement_Variance_Vectors	vector	Vector indexed by Measurement Indices containing Kalman_Filter_Elements
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
P_Row_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices	vector	Data type of Compact H matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Element	function	Extracts an element of a P and Q Matrix
Row	function	Extracts a row of a P and Q matrix
Phi_P_Phi_ Transpose	function	Performs an ABA transpose on a Phi Matrix and a P and Q Matrix
"*"	function	A K Column Vector is multiplied by the transpose of a P Row vector, yielding a P and Q matrix
"-"	function	Two P and Q matrices are added, yielding a P and Q matrix
"+"	function	Add a state vector and a K column vector, yielding a state vector
"*"	function	Multiply a K column vector by a Kalman Filter Element, yielding a K column vector

3.3.3.2.9.2.4 LOCAL DATA

None.

3.3.3.2.9.2.5 PROCESS CONTROL

Not applicable.

3.3.3.2.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
with Kalman_Filter_Common_Parts;
separate (Kalman_Filter_Compact_H_Parts)
package body Kalman_Update is

   package P_Manager is new
             Kalman_Filter_Common_Parts.Error_Covariance_Matrix_Manager
                (Phi_Matrices     => Phi_Matrices,
                 P_And_Q_Matrices => P_And_Q_Matrices);

   package Update_P_And_X is new
             Sequentially_Update_Covariance_Matrix_And_State_Vector
                (State_Indices             => State_Indices,
                 Measurement_Indices       => Measurement_Indices,
                 Kalman_Filter_Elements    => Kalman_Filter_Elements,
                 P_Matrices                => P_And_Q_Matrices,
                 Measurement_Variance_Vectors
```

```
                                        => Measurement_Variance_Vectors,
                Measurement_Vectors     => Measurement_Vectors,
                P_Row_Vectors           => P_Row_Vectors,
                K_Column_Vectors        => K_Column_Vectors,
                State_Vectors           => State_Vectors,
                Compact_H_Matrices      => Compact_H_Matrices);

   Zero_State_Vector : State_Vectors := (others => 0.0);

end Kalman_Update;
```

3.3.3.2.9.2.7 UTILIZATION OF OTHER ELEMENTS

The following library units are with'd by this part:
1. Kalman_Filter_Common_Parts

UTILIZATION OF EXTERNAL ELEMENTS:

Packages:

The following table summarizes the external packages required by this part:

Name	Type	Source	Description
Covariance_Matrix_Manager	generic package	Kalman_Filter_Common	Manages the Covariance Matrix (P)

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

The following table summarizes the packages required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Sequentially_Update_Covariance_Matrix_And_State_Vector	generic package	parent	Updates the P matrix and X Vector

3.3.3.2.9.2.8 LIMITATIONS

None.

3.3.3.2.9.2.9 LLCSC DESIGN

None.

3.3.3.2.9.2.10 UNIT DESIGN

3.3.3.2.9.2.10.1 UPDATE UNIT DESIGN

This unit is a procedure which does the Kalman Update

3.3.3.2.9.2.10.1.1 REQUIREMENTS ALLOCATION

This parts meets CAMP Requirement R147.

3.3.3.2.9.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.9.2.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
X	State_Vectors	in/out	State Vector (X) to be updatd
P	P_And_Q_Matrices	in/out	Error Covariance Matrix (P) to be updated
Z	Measurement_ Vectors	in	Current Measurement Vector(Z)
Compact_H	Compact_H_ Matrices	in	Current Measurement Sensitivity Array (Compact H)
Measurement_ Variance	Measurement_ Variance_Vectors	in	Current Measurement Variance Array
Propagated_Phi	Phi_Matrices	in	Current value of the propagated State Transition Matrix
Propagated_Q	P_And_Q_Matrices	in	Current value of the propagated Process Noise Matrix

3.3.3.2.9.2.10.1.4 LOCAL DATA

None.

3.3.3.2.9.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.2.9.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
   procedure Update
                    (X                    : in out State_Vectors;
                     P                    : in out P_And_Q_Matrices;
                     Z                    : in     Measurement_Vectors;
                     Compact_H            : in     Compact_H_Matrices;
                     Measurement_Variance : in     Measurement_Variance_Vectors;
                     Propagated_Phi       : in     Phi_Matrices;
                     Propagated_Q         : in     P_And_Q_Matrices) is
   begin

--       -- Propagate the Error Covariance Matrix

         P_Manager.Initialize (Initial_P => P);

         P_Manager.Propagate (Propagated_Phi => Propagated_Phi,
                              Propagated_Q   => Propagated_Q);

         P := P_Manager.P;


--       -- If the state vector is not zero, multiply it by Propagated Phi

         if X /= Zero_State_Vector then

            X := Propagated_Phi * X;

         end if;


--       -- Update Error Covariance Matrix and State Vector

         Update_P_And_X.Update (P                    => P,
                                X                    => X,
                                Z                    => Z,
                                Compact_H            => Compact_H,
                                Measurement_Variance => Measurement_Variance);

   end Update;
```

3.3.3.2.9.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

The following table summarizes the subroutines and task entries required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
P_Manager	package	parent	Manages the Error Covariance matrix (it is an instantiation of part R146)
Update_P_And_X	package	parent	Updates the Covariance Matrix and X Vector (it is an instantiation of part R152)

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements making up the Kalman Filter aggregates
Phi_Matrices	private	Data type of Phi matrix
P_And_Q_Matrices	private	Data type of a P and Q matrix
Measurement_Variance_Vectors	vector	Vector indexed by Measurement Indices containing Kalman_Filter_Elements
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices	vector	Data type of Compact H matrix

Data objects:

The following table summarizes the objects required by this part and defined elsewhere in the parent top level component:

Name	Type	Value	Description
Zero_State_Vector	State_Vector	vector of 0 values	Used for comparison to zero vector

3.3.3.2.9.2.10.1.8 LIMITATIONS

None.

3.3.3.2.10 UNIT DESIGN

3.3.3.2.10.1 COMPUTE_KALMAN_GAIN UNIT DESIGN (CATALOG #P138-0)

This unit is a generic function body which computes the Kalman gain vector resulting from the processing of a single component of the measurement vector, Z.

3.3.3.2.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R149.

3.3.3.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal data types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type of P matrix
Measurement_Variance_Vectors	vector	Vector indexed by Measurement Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices	vector	Data type of Compact H matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Element	function	Extracts an element of a P Matrix

3.3.3.2.10.1.4 LOCAL DATA

None.

3.3.3.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Compact_H_Parts)
function Compute_Kalman_Gain
            (P                    : P_Matrices;
             Measurement_Number   : Measurement_Indices;
             Compact_H            : Compact_H_Matrices;
             Measurement_Variance : Measurement_Variance_Vectors)
          return K_Column_Vectors is

   J : State_Indices;
   K : K_Column_Vectors;

begin

   J := Compact_H (Measurement_Number);

   for I in State_Indices loop

      K (I) := Element (P, I, J) /
               (Element (P, J, J) + Measurement_Variance (Measurement_Number));

   end loop;

   return K;

end Compute_Kalman_Gain;
```

3.3.3.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.2.10.1.8 LIMITATIONS

None.

3.3.3.2.10.2 UPDATE_ERROR_COVARIANCE_MATRIX UNIT DESIGN (CATALOG #P139-0)

This unit is a generic procedure body which computes the updated covariance matrix resulting from the processing of a single component of the measurement vector, Z.

3.3.3.2.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R150.

3.3.3.2.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal data types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type of P matrix
P_Row_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices	vector	Data type of Compact H matrix

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Row	function	Extracts a row of a P matrix
"*"	function	A K Column Vector is multiplied by the transpose of a P Row vector, yielding a P matrix
"-"	function	Two P matrices are added, yielding a Symmetric matrix

3.3.3.2.10.2.4 LOCAL DATA

None.

3.3.3.2.10.2.5 PROCESS CONTROL

Not applicable.

3.3.3.2.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Compact_H_Parts)

procedure Update_Error_Covariance_Matrix
                (P                  : in out P_Matrices;
                 Measurement_Number : in     Measurement_Indices;
                 K                  : in     K_Column_Vectors;
                 Compact_H          : in     Compact_H_Matrices) is

   J : State_Indices;

begin

   J := Compact_H (Measurement_Number);

   P := P - K * Row (P, J);

end Update_Error_Covariance_Matrix;
```

3.3.3.2.10.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.2.10.2.8 LIMITATIONS

None.

3.3.3.2.10.3 UPDATE_STATE_VECTOR UNIT DESIGN (CATALOG #P140-0)

This unit is a generic procedure body which updates the State Vector, X, given the old X vector, the Z vector, the K vector, the Measurement Number, and the Compact H array.

3.3.3.2.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R152.

3.3.3.2.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.10.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal data types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements making up the Kalman Filter aggregates
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
Compact_H_Matrices Vectors	vector	Vector indexed by Measurement_Indices containing State_Indices

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
"+"	function	Add a state vector and a K column vector, yielding a state vector
"*"	function	Multiply a K column vector by a Kalman Filter Element, yielding a K column vector

3.3.3.2.10.3.4 LOCAL DATA

None.

3.3.3.2.10.3.5 PROCESS CONTROL

Not applicable.

3.3.3.2.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Compact_H_Parts)
procedure Update_State_Vector
              (X                  : in out State_Vectors;
               Z                  : in     Measurement_Vectors;
               K                  : in     K_Column_Vectors;
               Measurement_Number : in     Measurement_Indices;
               Compact_H          : in     Compact_H_Matrices) is

   J : State_Indices;

begin

   J := Compact_H (Measurement_Number);

   X := K * (Z (Measurement_Number) - X (J)) + X;

end Update_State_Vector;
```

3.3.3.2.10.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.2.10.3.8 LIMITATIONS

None.

3.3.3.2.10.4 UPDATE_ERROR_COVARIANCE_MATRIX_GENERAL_FORM UNIT DESIGN (CATALOG #P1121-0)

This unit is a generic procedure body which computes the updated covariance matrix resulting from the processing of a single component of the measurement vector, Z.

3.3.3.2.10.4.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R150.

3.3.3.2.10.4.2 LOCAL ENTITIES DESIGN

None.

3.3.3.2.10.4.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table summarizes the generic formal data types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Type of covariance matrix. It represents a symmetric matrix index by (states, states)
K_H_Product_Matrices	private	A matrix of the form I_KH, where K is a K_Column_Vector and H is a row of the H matrix. It represents a matrix indexed by (states, states)
Measurement_Variance_	vector	Type of Measurement Variance Vector (R). It is indexed by (states)
K_Column_Vectors	vector	Type of a Column of the Kalman Gain Matrix (K). It is indexed by (states)
Compact_H_Matrices	vector	A vector, index by Measurement_Indices containing the indices of the measured states. It represents a matrix indexed by (Measurement, states) that is all zeroes except for locations specified by row=I, column= Compact_H_Matrices(I)

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
I_Minus_Column_ Matrix	function	K and the current state measured (as indicated by whicvh element of the current row of H is a "1") => I_KH
A_B_A_Transpose	function	K_H_Product Matrices * Kalman_Filter Elements * transpose(K_H_Product_ Matrices) => P_Matrices
A_B_A_Transpose	function	K_Colunm_Vectors * Kalman_Filter_ Elements * transpose(K_Column_ Vectors) => P_Matrices
"+"	function	P_Matrices + P_Matrices => P_Matrices

3.3.3.2.10.4.4 LOCAL DATA

None.

3.3.3.2.10.4.5 PROCESS CONTROL

Not applicable.

3.3.3.2.10.4.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Compact_H_Parts)

procedure Update_Error_Covariance_Matrix_General_Form
            (P                    : in out P_Matrices;
             Measurement_Number   : in     Measurement_Indices;
             K                    : in     K_Column_Vectors;
             Compact_H            : in     Compact_H_Matrices;
             Measurement_Variance : in     Measurement_Variance_Vectors) is

   I_Minus_K_H_Matrix : K_H_Product_Matrices;
   J                  : State_Indices;

begin

   J := Compact_H (Measurement_Number);

   I_Minus_K_H_Matrix := I_Minus_Column_Matrix (K             => K,
                                                State_Measure => J);

   P := ABA_Transpose (I_Minus_K_H_Matrix, P) +
        ABA_Transpose (K, Measurement_Variance( Measurement_Number ));

end Update_Error_Covariance_Matrix_General_Form;
```

3.3.3.2.10.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.2.10.4.8 LIMITATIONS

None.

```
package body Kalman_Filter_Compact_H_Parts is

   function Compute_Kalman_Gain
               (P                    : P_Matrices;
                Measurement_Number   : Measurement_Indices;
                Compact_H            : Compact_H_Matrices;
                Measurement_Variance : Measurement_Variance_Vectors)
            return K_Column_Vectors is separate;

   procedure Update_Error_Covariance_Matrix
               (P                  : in out P_Matrices;
                Measurement_Number : in     Measurement_Indices;
                K                  : in     K_Column_Vectors;
                Compact_H          : in     Compact_H_Matrices)
               is separate;

   procedure Update_State_Vector
               (X                  : in out State_Vectors;
                Z                  : in     Measurement_Vectors;
                K                  : in     K_Column_Vectors;
                Measurement_Number : in     Measurement_Indices;
                Compact_H          : in     Compact_H_Matrices)
               is separate;

   package body Sequentially_Update_Covariance_Matrix_And_State_Vector
                  is separate;

   package body Kalman_Update is separate;

   procedure Update_Error_Covariance_Matrix_General_Form
               (P                    : in out P_Matrices;
                Measurement_Number   : in     Measurement_Indices;
                K                    : in     K_Column_Vectors;
                Compact_H            : in     Compact_H_Matrices;
                Measurement_Variance : in     Measurement_Variance_Vectors)
            is separate;

end Kalman_Filter_Compact_H_Parts;
```

```
separate (Kalman_Filter_Compact_H_Parts)
function Compute_Kalman_Gain
            (P                    : P_Matrices;
             Measurement_Number   : Measurement_Indices;
             Compact_H            : Compact_H_Matrices;
             Measurement_Variance : Measurement_Variance_Vectors)
          return K_Column_Vectors is

   J : State_Indices;
   K : K_Column_Vectors;

begin

   J := Compact_H (Measurement_Number);

   for I in State_Indices loop

      K (I) := Element (P, I, J) /
               (Element (P, J, J) + Measurement_Variance (Measurement_Number));

   end loop;

   return K;

end Compute_Kalman_Gain;
```

```
separate (Kalman_Filter_Compact_H_Parts)

procedure Update_Error_Covariance_Matrix
                (P                  : in out P_Matrices;
                 Measurement_Number : in     Measurement_Indices;
                 K                  : in     K_Column_Vectors;
                 Compact_H          : in     Compact_H_Matrices) is

   J : State_Indices;

begin

   J := Compact_H (Measurement_Number);

   P := P - K * Row (P, J`·

end Update_Error_Covariance_Matrix;
```

```
separate (Kalman_Filter_Compact_H_Parts)
procedure Update_State_Vector
              (X                  : in out State_Vectors;
               Z                  : in     Measurement_Vectors;
               K                  : in     K_Column_Vectors;
               Measurement_Number : in     Measurement_Indices;
               Compact_H          : in     Compact_H_Matrices) is

   J : State_Indices;

begin

   J := Compact_H (Measurement_Number);

   X := K * (Z (Measurement_Number) - X (J)) + X;

end Update_State_Vector;
```

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```
separate (Kalman_Filter_Compact_H_Parts)
package body Sequentially_Update_Covariance_Matrix_And_State_Vector is

   K : K_Column_Vectors;


   function Compute_K is new Compute_Kalman_Gain
               (State_Indices           => State_Indices,
                Measurement_Indices     => Measurement_Indices,
                Kalman_Filter_Elements  => Kalman_Filter_Elements,
                P_Matrices              => P_Matrices,
                Measurement_Variance_Vectors
                                        => Measurement_Variance_Vectors,
                K_Column_Vectors        => K_Column_Vectors,
                Compact_H_Matrices      => Compact_H_Matrices);

   procedure Update_P is new Update_Error_Covariance_Matrix
               (State_Indices           => State_Indices,
                Measurement_Indices     => Measurement_Indices,
                Kalman_Filter_Elements  => Kalman_Filter_Elements,
                P_Matrices              => P_Matrices,
                P_Row_Vectors           => P_Row_Vectors,
                K_Column_Vectors        => K_Column_Vectors,
                Compact_H_Matrices      => Compact_H_Matrices);


   procedure Update_X is new Update_State_Vector
               (State_Indices           => State_Indices,
                Measurement_Indices     => Measurement_Indices,
                Kalman_Filter_Elements  => Kalman_Filter_Elements,
                Measurement_Vectors     => Measurement_Vectors,
                K_Column_Vectors        => K_Column_Vectors,
                State_Vectors           => State_Vectors,
                Compact_H_Matrices      => Compact_H_Matrices);

                                                          pragma PAGE;
   procedure Update
                (P                    : in out P_Matrices;
                 X                    : in out State_Vectors;
                 Z                    : in     Measurement_Vectors;
                 Compact_H            : in     Compact_H_Matrices;
                 Measurement_Variance : in     Measurement_Variance_Vectors) is

   begin

      for Measurement_Number in Measurement_Indices loop

         K := Compute_K (P                    => P,
                         Measurement_Number   => Measurement_Number,
                         Compact_H            => Compact_H,
                         Measurement_Variance => Measurement_Variance);

         Update_P (P                  => P,
                   Measurement_Number => Measurement_Number,
                   K                  => K,
                   Compact_H          => Compact_H);
```

```
         Update_X (X                  => X,
                   Z                  => Z,
                   K                  => K,
                   Measurement_Number => Measurement_Number,
                   Compact_H          => Compact_H);

      end loop;

   end Update;

end Sequentially_Update_Covariance_Matrix_And_State_Vector;
```

```
with Kalman_Filter_Common_Parts;
separate (Kalman_Filter_Compact_H_Parts)
package body Kalman_Update is

   package P_Manager is new
             Kalman_Filter_Common_Parts.Error_Covariance_Matrix_Manager
                (Phi_Matrices     => Phi_Matrices,
                 P_And_Q_Matrices => P_And_Q_Matrices);

   package Update_P_And_X is new
             Sequentially_Update_Covariance_Matrix_And_State_Vector
                (State_Indices             => State_Indices,
                 Measurement_Indices       => Measurement_Indices,
                 Kalman_Filter_Elements    => Kalman_Filter_Elements,
                 P_Matrices                => P_And_Q_Matrices,
                 Measurement_Variance_Vectors
                                           => Measurement_Variance_Vectors,
                 Measurement_Vectors       => Measurement_Vectors,
                 P_Row_Vectors             => P_Row_Vectors,
                 K_Column_Vectors          => K_Column_Vectors,
                 State_Vectors             => State_Vectors,
                 Compact_H_Matrices        => Compact_H_Matrices);

   Zero_State_Vector : State_Vectors := (others => 0.0);

                                                          pragma PAGE;
   procedure Update
                  (X                    : in out State_Vectors;
                   P                    : in out P_And_Q_Matrices;
                   Z                    : in     Measurement_Vectors;
                   Compact_H            : in     Compact_H_Matrices;
                   Measurement_Variance : in     Measurement_Variance_Vectors;
                   Propagated_Phi       : in     Phi_Matrices;
                   Propagated_Q         : in     P_And_Q_Matrices) is
   begin

--    -- Propagate the Error Covariance Matrix

      P_Manager.Initialize (Initial_P => P);

      P_Manager.Propagate (Propagated_Phi => Propagated_Phi,
                           Propagated_Q   => Propagated_Q);

      P := P_Manager.P;


--    -- If the state vector is not zero, multiply it by Propagated Phi

      if X /= Zero_State_Vector then

         X := Propagated_Phi * X;

      end if;


--    -- Update Error Covariance Matrix and State Vector
```

```
      Update_P_And_X.Update (P                  => P,
                             X                  => X,
                             Z                  => Z,
                             Compact_H          => Compact_H,
                             Measurement_Variance => Measurement_Variance);

   end Update;

end Kalman_Update;
```

```
separate (Kalman_Filter_Compact_H_Parts)

procedure Update_Error_Covariance_Matrix_General_Form
            (P                    : in out P_Matrices;
             Measurement_Number   : in     Measurement_Indices;
             K                    : in     K_Column_Vectors;
             Compact_H            : in     Compact_H_Matrices;
             Measurement_Variance : in     Measurement_Variance_Vectors) is

   I_Minus_K_H_Matrix : K_H_Product_Matrices;
   J                  : State_Indices;

begin

   J := Compact_H (Measurement_Number);

   I_Minus_K_H_Matrix := I_Minus_Column_Matrix (K             => K,
                                                State_Measure => J);

   P := Aba_Transpose (I_Minus_K_H_Matrix, P) +
        Aba_Transpose (K, Measurement_Variance( Measurement_Number ));

end Update_Error_Covariance_Matrix_General_Form;
```

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3.3.3.3 KALMAN FILTER COMPLICATED H PARTS (BODY) TLCSC (CATALOG #P149-0)

This part, which is designed as an Ada package, contains bodies for all CAMP parts which can be used to implement a Kalman Filter when a complicated Measurement Sensitivity Matrix (Complicated H Matrix) is used

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.3.1 REQUIREMENTS ALLOCATION

The following chart summarizes the allocation of CAMP requirements to this

Tlcsc:

Name	Requirements Allocation
Compute_Kalman_Gain	R182
Update_Error_Covariance_Matrix	R183
Update_State_Vector	R184
Sequentially_Update_Covariance_Matrix_and_ State_Vector	R201
Kalman_Update	R181
Update_Error_Covariance_Matrix_General_Form	R183

3.3.3.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.3 INPUT/OUTPUT

None.

3.3.3.3.4 LOCAL DATA

None.

3.3.3.3.5 PROCESS CONTROL

Not applicable.

3.3.3.3.6 PROCESSING

The following describes the processing performed by this part:

```
package body Kalman_Filter_Complicated_H_Parts is

   function Compute_Kalman_Gain
               ( P                    : P_Matrices;
```

```
                Measurement_Number   : Measurement_Indices;
                Complicated_H        : H_Matrices;
                Measurement_Variance : Measurement_Variance_Vectors)
             return K_Column_Vectors is separate;

   procedure Update_Error_Covariance_Matrix
             (P                 : in out P_Matrices;
              Measurement_Number : in     Measurement_Indices;
              K                 : in     K_Column_Vectors;
              Complicated_H     : in     H_Matrices) is separate;

   procedure Update_State_Vector
             (X                 : in out State_Vectors;
              Z                 : in     Measurement_Vectors;
              K                 : in     K_Column_Vectors;
              Measurement_Number : in     Measurement_Indices;
              Complicated_H     : in     H_Matrices) is separate;

   package body Sequentially_Update_Covariance_Matrix_and_State_Vector is separate;

   package body Kalman_Update is separate;

   procedure Update_Error_Covariance_Matrix_General_Form
             ( P                  : in out P_Matrices;
               Measurement_Number  : in     Measurement_Indices;
               K                  : in     K_Column_Vectors;
               Complicated_H      : in     H_Matrices;
               Measurement_Variance : in     Measurement_Variance_Vectors )
          is separate;

end Kalman_Filter_Complicated_H_Parts;
```

3.3.3.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.3.8 LIMITATIONS

None.

3.3.3.3.9 LLCSC DESIGN

3.3.3.3.9.1 SEQUENTIALLY UPDATE COVARIANCE MATRIX AND STATE VECTOR PACKAGE DESIGN (CATALOG #P153-0)

This LLCSC is a generic package which contains 1 procedure, "Update", which updates the Covariance Matrix, P, and state Vector, X.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.3.9.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R152.

3.3.3.3.9.1.2 LOCAL ENTITIES DESIGN

Packages:

As described above, this package body instantiates Compute Kalman Gain, Update Error Covariance Matrix, and Update State Vector

3.3.3.3.9.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
States_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type for n x n private P matrix
H_Matrices	private	Data type for private m x n H matrix
K_H_Product_Matrices	private	Data type for private n x n K and H matrix
H_Row_Vectors	private	Vector representing a row of a P matrix
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
Measurement_Variance_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Active_H_Vector	function	Returns the row of an (MxN) H matrix that is referenced
Subtract_From_ Identity	procedure	Subtracts a K and H Product matrix from the Identity Matrix(i.e., I - S)
Times_Transpose	function	Multiplies a P matrix by the transpose of a H Row Vector, yielding a K Column Vector
"*"	function	Multiplies a H Row Vector by a K Column vector, yielding a Kalman Filter Element
"*"	function	Multiplies a H Row Vector by a State vector, yielding a Kalman Filter Element
"*"	function	Multiplies a K Column Vector by a H Row Vector, yielding a K and H Product Matrix
"*"	function	Multiplies a K and H Product Matrix by a P Matrix, yielding a P Matrix
"*"	function	Multiplies a K Column Vector by a Kalman Filter Element, yielding a K Column Vector
"/"	function	Divides a K Column Vector by a Kalman Filter Element, yielding a K Column Vector
"+"	function	Adds a State Vector and a K Column Vector, yielding a State Vector

3.3.3.3.9.1.4 LOCAL DATA

None.

3.3.3.3.9.1.5 PROCESS CONTROL

Not applicable.

3.3.3.3.9.1.6 PROCESSING

The following describes the processing performed by this part:

separate (Kalman_Filter_Complicated_H_Parts)

```
package body Sequentially_Update_Covariance_Matrix_and_State_Vector is

   K : K_Column_Vectors;


   function Compute_K is new Compute_Kalman_Gain
               (State_Indices              => State_Indices,
                Measurement_Indices        => Measurement_Indices,
                Kalman_Filter_Elements     => Kalman_Filter_Elements,
                P_Matrices                 => P_Matrices,
                H_Matrices                 => H_Matrices,
                H_Row_Vectors              => H_Row_Vectors,
                Measurement_Variance_Vectors
                                           => Measurement_Variance_Vectors,
                K_Column_Vectors           => K_Column_Vectors);


   procedure Update_P is new Update_Error_Covariance_Matrix
               (State_Indices              => State_Indices,
                Measurement_Indices        => Measurement_Indices,
                Kalman_Filter_Elements     => Kalman_Filter_Elements,
                P_Matrices                 => P_Matrices,
                H_Matrices                 => H_Matrices,
                H_Row_Vectors              => H_Row_Vectors,
                K_H_Product_Matrices       => K_H_Product_Matrices,
                K_Column_Vectors           => K_Column_Vectors);


   procedure Update_X is new Update_State_Vector
               (State_Indices          => State_Indices,
                Measurement_Indices    => Measurement_Indices,
                Kalman_Filter_Elements => Kalman_Filter_Elements,
                H_Matrices             => H_Matrices,
                H_Row_Vectors          => H_Row_Vectors,
                Measurement_Vectors    => Measurement_Vectors,
                K_Column_Vectors       => K_Column_Vectors,
                State_Vectors          => State_Vectors);

end Sequentially_Update_Covariance_Matrix_and_State_Vector;
```

3.3.3.3.9.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Compute_Kalman_Gain	generic function	parent	Computes the Kalman Gain Vector, K
Update_State_Vector	generic procedure	parent	Updates the State Vector, X
Update_Error_Covariance_Matrix	generic procedure	parent	Updates the Error Covariance Matrix, P

3.3.3.3.9.1.8 LIMITATIONS

None.

3.3.3.3.9.1.9 LLCSC DESIGN

None.

3.3.3.3.9.1.10 UNIT DESIGN

3.3.3.3.9.1.10.1 UPDATE UNIT DESIGN

This unit is a procedure which does the update of the Covariance Matrix, P, and the State_Vector, X.

3.3.3.3.9.1.10.1.1 REQUIREMENTS ALLOCATION

This parts meets CAMP Requirement R201.

3.3.3.3.9.1.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.9.1.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
P	P_Matrices	in/out	Error Covariance Matrix (P) to be updated
X	State_Vectors	in/out	State Vector (X) to be updatd
Z	Measurement_ Vectors	in	Current Measurement Vector(Z)
Complicated_H	H_Matrices	in	Current Measurement Sensitivity Matrix (Complicated H)
Measurement_ Variance	Measurement_ Variance_	in	Current Measurement Variance Array

3.3.3.3.9.1.10.1.4 LOCAL DATA

None.

3.3.3.3.9.1.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.3.9.1.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
   procedure Update
               (P                    : in out P_Matrices;
                X                    : in out State_Vectors;
                Z                    : in     Measurement_Vectors;
                Complicated_H        : in     H_Matrices;
                Measurement_Variance : in     Measurement_Variance_Vectors) is
   begin

      for Measurement_Number in Measurement_Indices loop

         K := Compute_K (P                    => P,
                         Measurement_Number   => Measurement_Number,
                         Complicated_H        => Complicated_H,
                         Measurement_Variance => Measurement_Variance);

         Update_P (P                  => P,
                   Measurement_Number => Measurement_Number,
                   K                  => K,
                   Complicated_H      => Complicated_H);

         Update_X (X                  => X,
                   Z                  => Z,
                   K                  => K,
                   Measurement_Number => Measurement_Number,
```

```
                    Complicated_H      => Complicated_H);

      end loop;

   end Update;
```

3.3.3.3.9.1.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Subprograms and task entries:

The following table summarizes the subroutines and task entries required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Compute_Kalman_Gain	generic function	parent	Computes the Kalman Gain Vector, K
Update_State_Vector	generic procedure	parent	Updates the State Vector, X
Update_Error_Covariance_Matrix	generic procedure	parent	Updates the Error Covariance Matrix, P

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Base Type	Description
States_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type for n x n private P matrix
H_Matrices	private	Data type for private m x n H matrix
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
Measurement_Variance_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Data objects:

The following table summarizes the objects required by this part and defined elsewhere in the parent top level component:

Name	Type	Value	Description
K	K_Column_Vectors	variable	Stores the value of the Kalman Gain Vector (K)

3.3.3.3.9.1.10.1.8 LIMITATIONS

None.

3.3.3.3.9.2 KALMAN_UPDATE PACKAGE DESIGN (CATALOG #P155-0)

This LLCSC is a generic package which updates the State Vector, X, given the old X vector, the Z vector, the K vector, the Measurement Number, and the Complicated H array.

The decomposition for this part is the same as that shown in the Top-Level Design Document.

3.3.3.3.9.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R181.

3.3.3.3.9.2.2 LOCAL ENTITIES DESIGN

Packages:

As mentioned above, this package instantiates Sequentially Update Covariance Matrix and State Vector, and Error Covariance Matrix Manager

3.3.3.3.9.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
States_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
Phi_Matrices	private	Data type for private n x n Phi matrix
P_And_Q_Matrices	private	Data type for n x n private P matrix
H_Matrices	private	Data type for private m x n H matrix
K_H_Product_Matrices	private	Data type for private n x n K and H matrix
H_Row_Vectors	private	Vector representing a row of a P matrix
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
Measurement_Variance_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Active_H_Vector	function	Returns the row of an (MxN) H matrix that is referenced
Subtract_From_ Identity	procedure	Subtracts a K and H Product matrix from the Identity Matrix(i.e., I - S)
Times_Transpose	function	Multiplies a P matrix by the transpose of a H Row Vector, yielding a K Column Vector
Phi_P_Phi_	function	Does an ABA Transpose opertion on a Phi matrix and a P and Q matrix, yielding a P and Q matrix
"*"	function	Multiplies a H Row Vector by a K Column vector, yielding a Kalman Filter Element
"*"	function	Multiplies a H Row Vector by a State vector, yielding a Kalman Filter Element
"*"	function	Multiplies a K Column Vector by a H Row Vector, yielding a K and H Product Matrix
"*"	function	Multiplies a K and H Product Matrix by a P Matrix, yielding a P Matrix
"*"	function	Multiplies a K Column Vector by a Kalman Filter Element, yielding a K Column Vector
"*"	function	Multiplies a Phi Matrix by a State Vector yielding a State Vector
"/"	function	Divides a K Column Vector by a Kalman Filter Element, yielding a K Column Vector
"+"	function	Adds a State Vector and a K Column Vector, yielding a State Vector

3.3.3.3.9.2.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Zero_State_Vector	State_Vector	vector of 0 values	Used for comparison to zero vector

3.3.3.3.9.2.5 PROCESS CONTROL

Not applicable.

3.3.3.3.9.2.6 PROCESSING

The following describes the processing performed by this part:

```
with Kalman_Filter_Common_Parts;
separate (Kalman_Filter_Complicated_H_Parts)
package body Kalman_Update is

   package P_Manager is new
             Kalman_Filter_Common_Parts.Error_Covariance_Matrix_Manager
                ( Phi_Matrices     => Phi_Matrices,
                  P_And_Q_Matrices => P_And_Q_Matrices );

   package Update_P_And_X is new
             Sequentially_Update_Covariance_Matrix_And_State_Vector
                (State_Indices                => State_Indices,
                 Measurement_Indices          => Measurement_Indices,
                 Kalman_Filter_Elements       => Kalman_Filter_Elements,
                 P_Matrices                   => P_And_Q_Matrices,
                 H_Matrices                   => H_Matrices,
                 K_H_Product_Matrices         => K_H_Product_Matrices,
                 H_Row_Vectors                => H_Row_Vectors,
                 Measurement_Variance_Vectors => Measurement_Variance_Vectors,
                 Measurement_Vectors          => Measurement_Vectors,
                 K_Column_Vectors             => K_Column_Vectors,
                 State_Vectors                => State_Vectors );

   Zero_State_Vector : State_Vectors := (others => 0.0);

end Kalman_Update;
```

3.3.3.3.9.2.7 UTILIZATION OF OTHER ELEMENTS

The following library units are with'd by this part:
1. Kalman_Filter_Common_Parts

UTILIZATION OF EXTERNAL ELEMENTS:

Packages:

The following table summarizes the external packages required by this part:

Name	Type	Source	Description
Error_Covariance_Matrix_Manager	generic package	Kalman_Filter_Common_Parts	Manages the Covariance Matrix (P)

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

The following table summarizes the packages required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
Sequentially_Update_Covariance_Matrix_And_State_Vector	generic package	parent	Updates the P matrix and X Vector

3.3.3.3.9.2.8 LIMITATIONS

None.

3.3.3.3.9.2.9 LLCSC DESIGN

None.

3.3.3.3.9.2.10 UNIT DESIGN

3.3.3.3.9.2.10.1 UPDATE UNIT DESIGN

This unit is a procedure which does the Kalman Update

3.3.3.3.9.2.10.1.1 REQUIREMENTS ALLOCATION

This parts meets CAMP Requirement R181.

3.3.3.3.9.2.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.9.2.10.1.3 INPUT/OUTPUT

FORMAL PARAMETERS:

The following table describes this part's formal parameters:

Name	Type	Mode	Description
P	P_And_Q_Matrices	in/out	Error Covariance Matrix (P) to be updated
X	State_Vectors	in/out	State Vector (X) to be updatd
Z	Measurement_Vectors	in	Current Measurement Vector(Z)
Complicated_H	H_Matrices	in	Current Measurement Sensitivity Matrix (Complicated H)
Measurement_Variance	Measurement_Variance_Vectors	in	Current Measurement Variance Array
Propagated_Phi	Phi_Matrices	in	Current value of the propagated State Transition Matrix
Propagated_Q	P_And_Q_Matrices	in	Current value of the propagated Process Noise Matrix

3.3.3.3.9.2.10.1.4 LOCAL DATA

None.

3.3.3.3.9.2.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.3.9.2.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
   procedure Update (X                    : in out State_Vectors;
                     P                    : in out P_And_Q_Matrices;
                     Z                    : in     Measurement_Vectors;
                     Complicated_H        : in     H_Matrices;
                     Measurement_Variance : in     Measurement_Variance_Vectors;
                     Propagated_Phi       : in     Phi_Matrices;
                     Propagated_Q         : in     P_And_Q_Matrices) is

   begin

--     -- Propagate the Error Covariance Matrix
```

```
      P_Manager.Initialize (Initial_P => P);

      P_Manager.Propagate (Propagated_Phi => Propagated_Phi,
                           Propagated_Q   => Propagated_Q);

      P := P_Manager.P;

--    -- If the state vector is not zero, multiply it by Propagated Phi

      if X /= Zero_State_Vector then

         X := Propagated_Phi * X;

      end if;

--    -- Update Error Covariance Matrix and State Vector

      Update_P_And_X.Update (P                    => P,
                             X                    => X,
                             Z                    => Z,
                             Complicated_H        => Complicated_H,
                             Measurement_Variance => Measurement_Variance);

   end Update;
```

3.3.3.3.9.2.10.1.7 UTILIZATION OF OTHER ELEMENTS

UTILIZATION OF OTHER ELEMENTS IN TOP LEVEL COMPONENT:

The following tables describe the elements used by this part but defined elsewhere in the parent top level component:

Packages:

The following table summarizes the subroutines and task entries required by this part and defined elsewhere in the parent top level component:

Name	Type	Source	Description
P_Manager	package	Kalman_ Filter_ Common_ Parts	Manages the Error Covariance matrix (it is an instantiation of part R146)
Update_P_And_X	package	parent	Updates the Covariance Matrix and X Vector (it is an instantiation of part R201)

Data types:

The following table summarizes the types required by this part and defined elsewhere in the parent top level component:

Name	Base Type	Description
States_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
Phi_Matrices	private	Data type for private n x n Phi matrix
P_And_Q_Matrices	private	Data type for n x n private P matrix
H_Matrices	private	Data type for private m x n H matrix
K_H_Product_Matrices	private	Data type for private n x n K and H matrix
H_Row_Vectors	private	Vector representing a row of a P matrix
Measurement_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
Measurement_Variance_Vectors	vector	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Data objects:

The following table summarizes the objects required by this part and defined elsewhere in the parent top level component:

Name	Type	Value	Description
Zero_State_Vector	State_Vectors	vector of 0 values	Used for comparison to zero vector

3.3.3.3.9.2.10.1.8 LIMITATIONS

None.

3.3.3.3.10 UNIT DESIGN

3.3.3.3.10.1 COMPUTE_KALMAN_GAIN (BODY) UNIT DESIGN (CATALOG #P150-0)

This LLCSC is a generic function body which computes the Kalman gain vector resulting from the processing of a single component of the measurement vector, Z.

3.3.3.3.10.1.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R182.

3.3.3.3.10.1.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.10.1.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type for n x n P matrixx
H_Matrices	private	Data type for n x n H matrix
H_Row_Vectors	private	Data type of vector representing an H vector
Measurement_Variance_Vectors	array	Vector indexed by Measurement_Indices containing Kalman_Filter_Elements
K_Column_Vectors	array	Vector indexed by State_Indices containing Kalman_Filter_Elements

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Active_H_Vector	function	Returns the row of an (MxN) H matrix that is referenced
Times_Transpose	function	Multiplies a P matrix by the transpose of a n x 1 H Row Vector, yielding a K Column Vector
Dot_Product	function	Multiplies a (Nx1) H Row Vector by a K Column Vector, yielding a Kalman Filter Element
"/"	function	Divides a (Nx1) K Column Vector by a Kalman Filter Element, yielding a K Column Vector

3.3.3.3.10.1.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
Denominator	Kalman_Filter_Elements	variable	One element of the Error Covariance matrix
K	K_Column_Vectors	variable	Vector which is calculated and returned
V	H_Row_Vectors	variable	Column slice of the H matrix representing the current measurement

3.3.3.3.10.1.5 PROCESS CONTROL

Not applicable.

3.3.3.3.10.1.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Complicated_H_Parts)

function Compute_Kalman_Gain
            (P                    : P_Matrices;
             Measurement_Number   : Measurement_Indices;
             Complicated_H        : H_Matrices;
             Measurement_Variance : Measurement_Variance_Vectors)
            return K_Column_Vectors is


   Denominator : Kalman_Filter_Elements;
   K           : K_Column_Vectors;
   V           : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   K := Times_Transpose (Left  => P,
                         Right => V);

   Denominator := Dot_Product(Left  => V,
                              Right => K) +
                  Measurement_Variance( Measurement_Number );

   return K / Denominator;

end Compute_Kalman_Gain;
```

3.3.3.3.10.1.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.3.10.1.8 LIMITATIONS

None.

3.3.3.3.10.2 UPDATE_ERROR_COVARIANCE_MATRIX (BODY) UNIT DESIGN (CATALOG #P151-0)

This unit is a generic procedure body which computes the updated covariance matrix resulting from the processing of a single component of the measurement vector, Z.

3.3.3.3.10.2.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R183.

3.3.3.3.10.2.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.10.2.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type for private n x n P matrix
H_Matrices	private	Data type for private H matrix
H_Row_Vectors	private	Private vector representing a row of the H matrix
K_H_Product_Matrices	array	Private matrix representing product of K and H matrices
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Active_H_Vector	function	Returns the row of a (MxN) H Matrix that is referenced
Subtract_From_Identity	procedure	Subtracts a K_H_Product matrix from the Identity Matrix (i.e., I - S)
"*"	function	Multiplies a K Column Vector by a H Row Vector, yielding a K H Product Matrix
"*"	function	Multiplies a K H Product Matrix by a P Matrix, yielding a P Matrix

3.3.3.3.10.2.4 LOCAL DATA

None.

3.3.3.3.10.2.5 PROCESS CONTROL

Not applicable.

3.3.3.3.10.2.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Complicated_H_Parts)

procedure Update_Error_Covariance_Matrix
            (P                  : in out P_Matrices;
             Measurement_Number : in     Measurement_Indices;
             K                  : in     K_Column_Vectors;
             Complicated_H      : in     H_Matrices) is

   V : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   P := Subtract_From_Identity (K * V) * P;

end Update_Error_Covariance_Matrix;
```

3.3.3.3.10.2.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.3.10.2.8 LIMITATIONS

None.

3.3.3.3.10.3 UPDATE_STATE_VECTOR UNIT DESIGN (CATALOG #P152-0)

This unit is a generic procedure which updates the State Vector, X, given the old X vector, the Z vector, the K vector, the Measurement Number, and the Complicated H array.

3.3.3.3.10.3.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R184.

3.3.3.3.10.3.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.10.3.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
H_Matrices	private	Data type of m x n H matrix
H_Row_Vectors	private	Vector representing a row of an H matrix
Measurement_Vectors	vector	Vector indexed by Measurement Indices
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements
State_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Active_H_Vector	function	Returns the row of a (MxN) H matrix that is referenced
"*"	function	Computes the product of an H Row vector and a State vector, yeilding a Kalman Filter Element
Dot_Product	function	Multiplies a (Nx1) K Column Vector by a Kalman Filter Element, yielding a K Column Vector
"+"	function	Adds a state vector and a K column vector (both n x 1) yielding a state vector

3.3.3.3.10.3.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
V	H_Row_Vectors	variable	Column slice of the H matrix representing the current measurement

3.3.3.3.10.3.5 PROCESS CONTROL

Not applicable.

3.3.3.3.10.3.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Complicated_H_Parts)
procedure Update_State_Vector
             (X                  : in out State_Vectors;
              Z                  : in     Measurement_Vectors;
              K                  : in     K_Column_Vectors;
              Measurement_Number : in     Measurement_Indices;
              Complicated_H      : in     H_Matrices) is

   V : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
```

```
                        Row    => Measurement_Number);

   X := K * (Z (Measurement_Number) -
             Dot_Product(Left  => V,
                         Right => X)) + X;

end Update_State_Vector;
```

3.3.3.3.10.3.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.3.10.3.8 LIMITATIONS

None.

3.3.3.3.10.4 UPDATE_ERROR_COVARIANCE_MATRIX_GENERAL_FORM UNIT DESIGN (CATALOG #P1119-0)

This unit is a generic procedure body which computes the updated covariance matrix resulting from the processing of a single component of the measurement vector, Z. This solution uses the general form of the equation.

3.3.3.3.10.4.1 REQUIREMENTS ALLOCATION

This part meets CAMP requirement R183.

3.3.3.3.10.4.2 LOCAL ENTITIES DESIGN

None.

3.3.3.3.10.4.3 INPUT/OUTPUT

GENERIC PARAMETERS:

Data types:

The following table describes the generic formal types required by this part:

Name	Base Type	Description
State_Indices	discrete	Index to the arrays which depend on the number of states
Measurement_Indices	discrete	Index to the arrays which depend on the number of measurements
Kalman_Filter_Elements	floating point type	Elements contained in the Kalman Filter aggregates
P_Matrices	private	Data type for private n x n P matrix
H_Matrices	private	Data type for private H matrix
H_Row_Vectors	private	Private vector representing a row of the H matrix
K_H_Product_Matrices	array	Private matrix representing product of K and H matrices
Measurement_Variance_Vectors	array	Vector indixed by Measurement Indices containing KF Elements
K_Column_Vectors	vector	Vector indexed by State_Indices containing Kalman_Filter_Elements

Subprograms:

The following table summarizes the generic formal subroutines required by this part:

Name	Type	Description
Active_H_Vector	function	Returns the row of a (MxN) H Matrix that is referenced
Subtract_From_ Identity	procedure	Subtracts a K_H_Product matrix from the Identity Matrix (i.e., I - S)
ABA_Transpose	function	Does an ABA transpose on a K H Matrix and a P Matrix, yielding a P Matrix
ABA_Transpose	function	Does an ABA transpose on a K Column Vector and a Kalman Filter Element, yielding a P Matrix
"*"	function	Multiplies a K Column Vector by a H Row Vector, yielding a K H Product Matrix
"+"	function	Adds two P Matrices, yielding a P Matrix

3.3.3.3.10.4.4 LOCAL DATA

Data objects:

The following table describes the data objects maintained by this part:

Name	Type	Value	Description
A	K_H_Product_Matrices	variable	Product of K and H Matrices
V	H_Row_Vectors	variable	Column slice of the H matrix representing the current measurement

3.3.3.3.10.4.5 PROCESS CONTROL

Not applicable.

3.3.3.3.10.4.6 PROCESSING

The following describes the processing performed by this part:

```
separate (Kalman_Filter_Complicated_H_Parts)

procedure Update_Error_Covariance_Matrix_General_Form
            (P                    : in out P_Matrices;
```

```
            Measurement_Number   : in     Measurement_Indices;
            K                    : in     K_Column_Vectors;
            Complicated_H        : in     H_Matrices;
            Measurement_Variance : in     Measurement_Variance_Vectors ) is

   A : K_H_Product_Matrices;
   V : H_Row_Ve_tors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   A := Subtract_From_Identity (K * V);

   P := ABA_Transpose( A, P ) +
        ABA_Transpose( K, Measurement_Variance( Measurement_Number ) );

end Update_Error_Covariance_Matrix_General_Form;
```

3.3.3.3.10.4.7 UTILIZATION OF OTHER ELEMENTS

None.

3.3.3.3.10.4.8 LIMITATIONS

None.

```
package body Kalman_Filter_Complicated_H_Parts is

   function Compute_Kalman_Gain
               ( P                    : P_Matrices;
                 Measurement_Number   : Measurement_Indices;
                 Complicated_H        : H_Matrices;
                 Measurement_Variance : Measurement_Variance_Vectors)
              return K_Column_Vectors is separate;

   procedure Update_Error_Covariance_Matrix
               (P                  : in out P_Matrices;
                Measurement_Number : in     Measurement_Indices;
                K                  : in     K_Column_Vectors;
                Complicated_H      : in     H_Matrices) is separate;

   procedure Update_State_Vector
               (X                  : in out State_Vectors;
                Z                  : in     Measurement_Vectors;
                K                  : in     K_Column_Vectors;
                Measurement_Number : in     Measurement_Indices;
                Complicated_H      : in     H_Matrices) is separate;

   package body Sequentially_Update_Covariance_Matrix_And_State_Vector is separate;

   package body Kalman_Update is separate;

   procedure Update_Error_Covariance_Matrix_General_Form
               ( P                    : in out P_Matrices;
                 Measurement_Number   : in     Measurement_Indices;
                 K                    : in     K_Column_Vectors;
                 Complicated_H        : in     H_Matrices;
                 Measurement_Variance : in     Measurement_Variance_Vectors )
              is separate;

end Kalman_Filter_Complicated_H_Parts;
```

```
separate (Kalman_Filter_Complicated_H_Parts)

function Compute_Kalman_Gain
            (P                    : P_Matrices;
             Measurement_Number   : Measurement_Indices;
             Complicated_H        : H_Matrices;
             Measurement_Variance : Measurement_Variance_Vectors)
            return K_Column_Vectors is


   Denominator : Kalman_Filter_Elements;
   K           : K_Column_Vectors;
   V           : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   K := Times_Transpose (Left  => P,
                         Right => V);

   Denominator := Dot_Product(Left  => V,
                              Right => K) +
                  Measurement_Variance( Measurement_Number );

   return K / Denominator;

end Compute_Kalman_Gain;
```

```
separate (Kalman_Filter_Complicated_H_Parts)

procedure Update_Error_Covariance_Matrix
            (P                  : in out P_Matrices;
             Measurement_Number : in     Measurement_Indices;
             K                  : in     K_Column_Vectors;
             Complicated_H      : in     H_Matrices) is

   V : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   P := Subtract_From_Identity (K * V) * P;

end Update_Error_Covariance_Ma  ix;
```

```
separate (Kalman_Filter_Complicated_H_Parts)
procedure Update_State_Vector
            (X                  : in out State_Vectors;
             Z                  : in     Measurement_Vectors;
             K                  : in     K_Column_Vectors;
             Measurement_Number : in     Measurement_Indices;
             Complicated_H      : in     H_Matrices) is

   V : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   X := K * (Z (Measurement_Number) -
             Dot_Product(Left  => V,
                         Right => X)) + X;

end Update_State_Vector;
```

```
separate (Kalman_Filter_Complicated_H_Parts)

package body Sequentially_Update_Covariance_Matrix_And_State_Vector is

   K : K_Column_Vectors;


   function Compute_K is new Compute_Kalman_Gain
               (State_Indices              => State_Indices,
                Measurement_Indices        => Measurement_Indices,
                Kalman_Filter_Elements     => Kalman_Filter_Elements,
                P_Matrices                 => P_Matrices,
                H_Matrices                 => H_Matrices,
                H_Row_Vectors              => H_Row_Vectors,
                Measurement_Variance_Vectors
                                           => Measurement_Variance_Vectors,
                K_Column_Vectors           => K_Column_Vectors);


   procedure Update_P is new Update_Error_Covariance_Matrix
               (State_Indices              => State_Indices,
                Measurement_Indices        => Measurement_Indices,
                Kalman_Filter_Elements     => Kalman_Filter_Elements,
                P_Matrices                 => P_Matrices,
                H_Matrices                 => H_Matrices,
                H_Row_Vectors              => H_Row_Vectors,
                K_H_Product_Matrices       => K_H_Product_Matrices,
                K_Column_Vectors           => K_Column_Vectors);


   procedure Update_X is new Update_State_Vector
               (State_Indices          => State_Indices,
                Measurement_Indices    => Measurement_Indices,
                Kalman_Filter_Elements => Kalman_Filter_Elements,
                H_Matrices             => H_Matrices,
                H_Row_Vectors          => H_Row_Vectors,
                Measurement_Vectors    => Measurement_Vectors,
                K_Column_Vectors       => K_Column_Vectors,
                State_Vectors          => State_Vectors);
                                                          pragma PAGE;
   procedure Update
               (P                    : in out P_Matrices;
                X                    : in out State_Vectors;
                Z                    : in     Measurement_Vectors;
                Complicated_H        : in     H_Matrices;
                Measurement_Variance : in     Measurement_Variance_Vectors) is
   begin

      for Measurement_Number in Measurement_Indices loop

         K := Compute_K (P                    => P,
                         Measurement_Number   => Measurement_Number,
                         Complicated_H        => Complicated_H,
                         Measurement_Variance => Measurement_Variance);

         Update_P (P                  => P,
                   Measurement_Number => Measurement_Number,
```

```
                K                   => K,
                Complicated_H       => Complicated_H);

        Update_X (X                 => X,
                Z                   => Z,
                K                   => K,
                Measurement_Number  => Measurement_Number,
                Complicated_H       => Complicated_H);

     end loop;

   end Update;

end Sequentially_Update_Covariance_Matrix_And_State_Vector;
```

```
with Kalman_Filter_Common_Parts;
separate (Kalman_Filter_Complicated_H_Parts)
package body Kalman_Update is

   package P_Manager is new
             Kalman_Filter_Common_Parts.Error_Covariance_Matrix_Manager
                ( Phi_Matrices     => Phi_Matrices,
                  P_And_Q_Matrices => P_And_Q_Matrices );

   package Update_P_And_X is new
             Sequentially_Update_Covariance_Matrix_And_State_Vector
                (State_Indices                => State_Indices,
                 Measurement_Indices          => Measurement_Indices,
                 Kalman_Filter_Elements       => Kalman_Filter_Elements,
                 P_Matrices                   => P_And_Q_Matrices,
                 H_Matrices                   => H_Matrices,
                 K_H_Product_Matrices         => K_H_Product_Matrices,
                 H_Row_Vectors                => H_Row_Vectors,
                 Measurement_Variance_Vectors => Measurement_Variance_Vectors,
                 Measurement_Vectors          => Measurement_Vectors,
                 K_Column_Vectors             => K_Column_Vectors,
                 State_Vectors                => State_Vectors );

   Zero_State_Vector : State_Vectors := (others => 0.0);

pragma PAGE;
   procedure Update (X                    : in out State_Vectors;
                     P                    : in out P_And_Q_Matrices;
                     Z                    : in     Measurement_Vectors;
                     Complicated_H        : in     H_Matrices;
                     Measurement_Variance : in     Measurement_Variance_Vectors;
                     Propagated_Phi       : in     Phi_Matrices;
                     Propagated_Q         : in     P_And_Q_Matrices) is

   begin

--       -- Propagate the Error Covariance Matrix

      P_Manager.Initialize (Initial_P => P);

      P_Manager.Propagate (Propagated_Phi => Propagated_Phi,
                           Propagated_Q   => Propagated_Q);

      P := P_Manager.P;

--       -- If the state vector is not zero, multiply it by Propagated Phi

      if X /= Zero_State_Vector then

         X := Propagated_Phi * X;

      end if;

--       -- Update Error Covariance Matrix and State Vector

      Update_P_And_X.Update (P                    => P,
                             X                    => X,
```

```
                                Z                    => Z,
                                Complicated_H        => Complicated_H,
                                Measurement_Variance => Measurement_Variance);

   end Update;

end Kalman_Update;
```

```
separate (Kalman_Filter_Complicated_H_Parts)

procedure Update_Error_Covariance_Matrix_General_Form
            (P                  : in out P_Matrices;
             Measurement_Number : in     Measurement_Indices;
             K                  : in     K_Column_Vectors;
             Complicated_H      : in     H_Matrices;
             Measurement_Variance : in   Measurement_Variance_Vectors ) is

   A : K_H_Product_Matrices;
   V : H_Row_Vectors;

begin

   V := Active_H_Vector (Source => Complicated_H,
                         Row    => Measurement_Number);

   A := Subtract_From_Identity (K * V);

   P := Aba_Transpose( A, P ) +
        Aba_Transpose( K, Measurement_Variance( Measurement_Number ) );

end Update_Error_Covariance_Matrix_General_Form;
```

SUPPLEMENTARY

INFORMATION

DEPARTMENT OF THE AIR FORCE
WRIGHT LABORATORY (AFSC)
EGLIN AIR FORCE BASE, FLORIDA, 32542-5434

ERRATA
AD-B120254

REPLY TO ATTN OF MNOI

13 Feb 92

SUBJECT Removal of Distribution Statement and Export-Control Warning Notices

TO Defense Technical Information Center
ATTN: DTIC/HAR (Mr William Bush)
Bldg 5, Cameron Station
Alexandria, VA 22304-6145

1. The following technical reports have been approved for public release by the local Public Affairs Office (copy attached).

Technical Report Number	AD Number
1. 88-18-Vol-4	ADB 120 251
2. 88-18-Vol-5	ADB 120 252
3. 88-18-Vol-6	ADB 120 253
4. 88-25-Vol-1	ADB 120 309
5. 88-25-Vol-2	ADB 120 310
6. 88-62-Vol-1	ADB 129 568
7. 88-62-Vol-2	ADB 129 569
8. 88-62-Vol-3	ADB 129-570
9. 85-93-Vol-1	ADB 102-654
10. 85-93-Vol-2	ADB 102-655
11. 85-93-Vol-3	ADB 102-656
12. 88-18-Vol-1	ADB 120 248
13. 88-18-Vol-2	ADB 120 249
14. 88-18-Vol-7	ADB 120 254
15. 88-18-Vol-8	ADB 120 255
16. 88-18-Vol-9	ADB 120 256
17. 88-18-Vol-10	ADB 120 257
18. 88-18-Vol-11	ADB 120 258
19. 88-18-Vol-12	ADB 120 259

2. If you have any questions regarding this request call me at DSN 872-4620.

LYNN S. WARGO
Chief, Scientific and Technical
Information Branch

1 Atch
AFDTIC/PA Ltr, dtd 30 Jan 92

ERRATA

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE DEVELOPMENT TEST CENTER (AFSC)
EGLIN AIR FORCE BASE, FLORIDA 32542-5000

REPLY TO
ATTN OF: PA (Jim Swinson, 882-3931) 30 January 1992

SUBJECT: Clearance for Public Release

TO: WL/MNA

The following technical reports have been reviewed and are approved for public release: AFATL-TR-88-18 (Volumes 1 & 2), AFATL-TR-88-18 (Volumes 4 thru 12), AFATL-TR-88-25 (Volumes 1 & 2), AFATL-TR-88-62 (Volumes 1 thru 3) and AFATL-TR-85-93 (Volumes 1 thru 3).

Virginia N. Pribyla

VIRGINIA N. PRIBYLA, Lt Col, USAF
Chief of Public Affairs

AFDTC/PA 92-039