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Code 591.0

**PACE**

**Guidance Navigation & Control (GN&C)**

**Flight Software Sustaining Engineering (FSSE) Plan**

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**PACE GN&C Flight Software Sustaining Engineering Plan**

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Preface

This document is under Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Mission configuration control. Changes to this document require prior approval of the PACE Configuration Control Board (CCB) Chairperson or designee. Submit proposed changes to the PACE Configuration Management Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

Change History Log

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# Introduction

## Purpose

For the PACE mission, the Attitude Control Systems (ACS) onboard software is generated using MATLAB and Simulink autogenerated C code. The ACS onboard software autogenerated C code is owned and maintained by GSFC 0591. This PACE GNC Flight Software Sustaining Engineer (FSSE) Plan defines the civil servant level of effort and procurement resources required to support the Code 0582 PACE FSSE team with software updates post commissioning.

## Scope

This document defines the required personnel and procurement resources required for ACS to provide post commissioning support to the PACE project. This includes PACE ACS HiFi simulation analysis, GNC FSW build generation, ground testing, on orbit verification, and anomaly support for the duration of the PACE mission.

## PACE Mission Overview

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission is a strategic climate continuity mission that was defined in the 2010 document *Responding to the Challenge of Climate and Environmental Change: NASA’s Plan for Climate-Centric Architecture for Earth Observations and Applications from Space* (referred to as the “Climate Initiative”). The Climate Initiative complements NASA’s implementation of the National Research Council’s 2007 and 2017 Decadal Surveys of Earth Science at NASA, NOAA, and USGS, entitled *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* and *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space*, respectively.

PACE will extend the high quality ocean ecological, ocean biogeochemical, cloud, and aerosol particle data records begun by NASA in the 1990s, building on the heritage of the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging SpectroRadiometer (MISR), and the Visible Infrared Imaging Radiometer Suite (VIIRS). The mission will be capable of collecting radiometric and polarimetric measurements of the ocean and atmosphere, from which these biological, biogeochemical, and physical properties will be determined. PACE data products will not only add to existing critical climate and Earth system records, but also answer new and emerging advanced science questions related to Earth’s changing climate.

PACE is classified as a Category 2 mission, per the criteria in NASA Procedural Requirement (NPR) 7120.5E, NASA Space Flight Program and Project Management Requirements. The mission classification is C according to NPR 8705.4B, Risk Classification for NASA Payloads.

The PACE observatory is comprised of three instruments, an Ocean Color Instrument (OCI) and two polarimeters, the Hyper-Angular Rainbow Polarimeter 2 (HARP2) and the Spectro-Polarimeter for Exploration (SPEXone). The OCI is the primary instrument on the observatory and is being developed at Goddard Space Flight Center (GSFC). The OCI is a hyperspectral scanning radiometer designed to measure spectral radiances from the ultraviolet to shortwave infrared (SWIR) to enable advanced ocean color and heritage cloud and aerosol particle science.

The HARP2 and SPEXone are secondary instruments on the PACE observatory, acquired outside of GSFC.  The HARP2 is multi-spectral, wide swath (supporting atmospheric correction of OCI) and hyper-angular (good for clouds).  The SPEXone is narrow swath and hyperspectral, better for characterizing aerosol microphysical properties.

This three-instrument PACE mission has the following multiple scientific goals:

 Extending key systematic ocean biological, ecological, and biogeochemical climate data records and cloud and aerosol climate data records;

 Making global measurements of ocean color data products that are essential for understanding the global carbon cycle and ocean ecosystem responses to a changing climate;

 Collecting global observations of aerosol and cloud properties, focusing on reducing the largest uncertainties in climate and radiative forcing models of the Earth system; and,

 Improving our understanding of how aerosols influence ocean ecosystems and biogeochemical cycles and how ocean biological and photochemical processes affect the atmosphere.

The PACE satellite is planned for a launch in 2023-2024. The PACE project office at NASA’s GSFC is responsible for the satellite development, launch and operations. The mission is planned for launch into a Sun synchronous polar orbit at 676.5 km with an inclination of 98 degrees and a 1 pm local ascending node crossing time. The spacecraft bus will host the OCI, HARP2, and SPEXone instruments. The GSFC PACE Project office will oversee the mission and the development of the satellite, launch vehicle, mission operations control center, and operations. The NASA Headquarters Program Science will separately fund the science data processing system and competed science teams, which will include field-based vicarious calibration and data product validation efforts to support the Project science team.

NASA Headquarters has directed the mission development to be guided by a Design-to-Cost (DTC) process. All elements of the mission, other than the cost, are in the DTC trade space. At the heart of the DTC process are the mission studies, performed across all the mission elements. The mission studies will be used to define appropriate approaches within and across elements while maximizing science capabilities at a high cost confidence. Mission baseline requirements development is also embedded within the DTC process, as these requirements were not established at the onset of the mission concept development. Baseline mission requirements will be a product of the mission studies and will be defined by the project office as part of the DTC process.

The PACE mission consists of four major segments: space segment (SS), ground segment (GS), science data segment (SDS), and the launch segment (LS).

* The space segment consists of the spacecraft bus, the OCI, and two polarimeters. The spacecraft and OCI are being developed and integrated at GSFC. The polarimeters are contributed instruments. The spacecraft and instruments will be integrated as the PACE observatory at GSFC.
* The GS and associated Mission Operations Center (MOC) will be developed, integrated, and operated at GSFC. The GS provides for the command and control and health and safety monitoring of the PACE observatory on-orbit, as well as ensuring the science data are accounted for and delivered to the SDS via the Data Acquisition Processing and Handling Environment (DAPHNE) Cloud.
* The MOC will house the flight operations team (FOT) and is being managed by the PACE project through observatory commissioning. After commissioning, the FOT will be managed by the GSFC Earth Science Mission Operations (ESMO) project. The MOC performs all real time operations and off-line operations functions, including planning and scheduling, orbit and attitude analysis, housekeeping telemetry data processing, monitoring/managing the spacecraft and instruments, first line health/safety for the instruments, and housekeeping archiving and analysis.
* The SDS will be located at GSFC, but managed (separately from the project) by the NASA Headquarters Earth Sciences Division. The SDS will ingest, apply calibration and science algorithms, and process the science data, provide science software development and algorithm integration, act as the science data interface to the science team, and deliver all science data products to the NASA-assigned Distributed Active Archive Center (DAAC).
* The LS consists of the SpaceX Falcon 9 launch vehicle that was procured by the NASA Launch Services Program at Kennedy Space Center (KSC). The launch site is planned to be at the Cape Canaveral Air Force Station.

The project will utilize the NASA/GSFC institutional capabilities such as the Flight Dynamics Facility (FDF), the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) project, the Ocean Biology Processing Group (OBPG), the Space Network (SN), and the NASA Integrated Services Network (NISN). PACE plans to generate 3.5 Terabits of science data daily. The data are downlinked from the observatory during 12-14 daily contacts via Ka-band communications to the ACCESS Direct to Earth (DTE) ground stations. The observatory will also receive ground commands and transmit real-time housekeeping telemetry via a S-band 2-way link through the DTE during nominal operations. The observatory also has the capability of receiving ground commands and transmitting real-time housekeeping telemetry, via S-Band, through the ACCESS Space Relay (SR) during critical or contingency operations.

## Related Documentation

### Applicable Documents

PACE-FSW-ICD-0107 PACE Attitude Control System (ACS) Software to Flight Software Sustaining Engineering (FSSE) Interface Agreement (IA)

### Reference Documents

# General

## FTE Requirements

If updates to PACE ACS flight software code or parameters are required, GSFC Code 0591 will provide civil servant support to produce the code or parameter updates. It is the responsibility of 0591 to ensure that the engineer working any FSSE activities has the experience and technical capability to perform the activity. Any changes to PACE ACS flight software code or parameters would likely need to be supported by analysis in the ACS High Fidelity (HiFi) model. The FTE requirements defined in this document include that analysis task. The labor required to maintain and update the HiFi repository is included as well.

While the PACE mission is only planned to operate for 3 years, this plan proposes FTE support for the next 5 years to allow for mission extensions.

ACS requires that the PACE project maintain 0.3 FTE for the purposes of flight software sustaining engineering for fiscal year 2024 and FY 2028. The most likely time for additional analysis, flight software changes, and anomaly support are early in the mission, and after a few years have passed as hardware issues arise. This accounts for the 1st and 5th year in the plan. The value is meant to be conservative.

ACS requires that the PACE project maintain 0.2 FTE for the purposes of FSSE for the fiscal years 2025, 2026, and 2027. This value is based on 591 FTE charging for the year when GPM experienced a reaction wheel failure requiring ACS support. The value is meant to be conservative.

## License Requirements

The HiFi model and associated ACS flight software is developed and maintained in MATLAB Simulink 2019b. While MATLAB and Simulink are designed to backward compatible, there is no guarantee that the build generation process will work in other versions. It is the responsibility of Code 500 IT to ensure that MATLAB 2019b is available to PACE FSSE each year. The following licenses are required to run the HiFi model, as well as to generate the ACS flight software build deliveries to Code 0582 PACE FSSE team. All toolboxes are in reference to MATLAB’s toolbox suite.

* MATLAB 2019b
* Simulink 2019b
* Controls Toolbox
* Aerospace Toolbox
* Simulink Aerospace Blockset
* Ephemeris Data for Aerospace toolbox

MATLAB Coder

* Real-Time Workshop
* RTW Embedded Coder
* Simulink Verification Validation

The licenses required are provided through the GSFC Code 0500 network pool. In the event that ACS analysis or flight software code/parameter changes are needed, the ACS engineer assigned to perform the task will be able to pull from the Code 0500 network pool. PACE Ground Systems is required to budget $8000 per year to maintain the one FSSE network license in the Code 0500 network pool. This cost is capped each year.

## Repository Management

**PACE ACS maintains a GITLAB account managed by Code 500 IT. The GITLAB includes a full account of open and closed issues for PACE ACS during its development, integration, and testing. It also includes a wiki with test results, hardware component overviews, activity cheat sheets and many other features of PACE ACS. The full HiFi model and flight software code repository is hosted and configuration managed on the PACE ACS GITLAB. Access to the PACE ACS GITLAB will be maintained by code 500 IT after PACE commissioning. The FSSE ACS engineer tasked with flight software build generation or analysis will access PACE ACS HiFi through the PACE ACS GITLAB. The PACE ACS GITLAB contains a full version history of content, including the wiki. Previous versions can be reverted to at any time and changes tracked.**

## Build Generation

**Any changes to the onboard FSW must be approved by the Code 0582 FSSE Change Control Board (CCB), including changes to the ACS FSW. In addition to the work and approval of the ACS FSSE engineer, all post-commissioning changes to the ACS FSW will be approved and vetted by Code 0591 discipline experts or branch managers through table-top reviews.**

**The detailed instructions for generating a new ACS FSW build from the PACE ACS HiFi model are located on the PACE ACS GITLAB, including a full video demonstration for generating and delivering a build. Note that ACS delivers the generated C files, not the binary files, to the FSSE team. It is the responsibility of FSSE and FSW to convert the C files into binary files to be integrated into an overall onboard FSW build.** Code 0582 is also responsible for performing the build tests at their FSW lab or FlatSat. Code 0591 will support data review of the build tests performed by Code 0582.

**Note that the full build generation process for ACS FSW code or parameter updates can take several hours depending on availability of a GITLAB pipeline runner or ACS FSSE engineer. If rapid changes to FSW table values are required, please refer to Flight Operation Procedure (FOP) SC SYS Table Value Modification, owned by the Flight Operations Team.**

## Build Testing

**Each merge request performed on the HiFi repository must pass a full code pipeline that runs a suite of unit tests on the ACS flight software. This process must be performed as well when generating a build. The full suite of unit tests can be found in the HiFi repository.**

**Historically on PACE, any changes to flight software code required level 5 requirements be written between ACS and FSW. The level 5 requirement must then be verified by test. A suite of FSW tests have been created by Code 0582 to support that verification evidence. This process will continue post PACE commissioning. Note that this only true for flight software code changes, and not parameter changes. Parameter changes are still verified by the ACS unit tests and FSW testing.**

Abbreviations and Acronyms

|  |  |
| --- | --- |
| ACS | Attitude Control System |
| FSSE | Flight Software Sustaining Engineering |
| FSW | Flight Software |
| GSFC | Goddard Space Flight Center |
| HiFi | ACS High Fidelity Model |
| ITAR | International Trade in Arms Regulation |
| SBU | Sensitive But Unclassified |
| TBD | To be determined |
| TBR | To be revised |
| TBS | To be scheduled |
|  |  |