NASA SmallSat LEARN Forum Briefing:

PACE (Payload Accelerator for CubeSat Endeavors)

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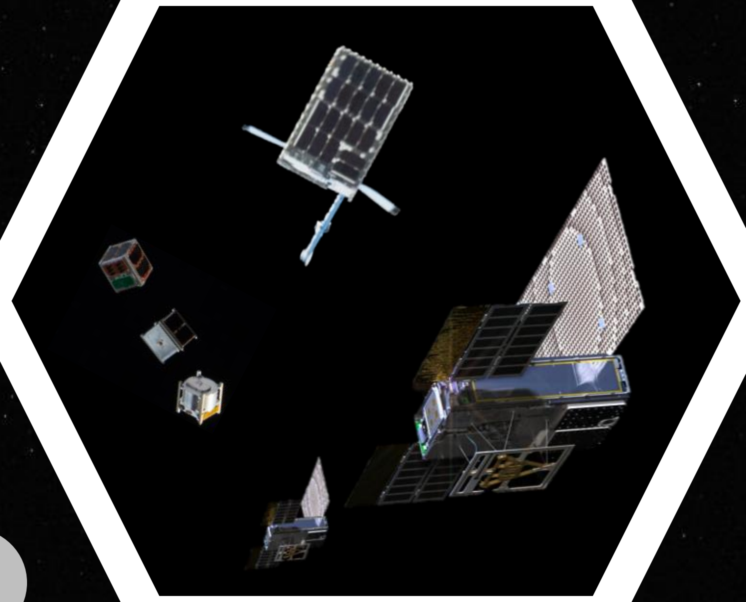


National Aeronautics and Space Administration Small Satellite Learning from Experience, Achievements and Resolution Navigation Forum

National Aeronautics and Space Administration

PACE-2 Overview

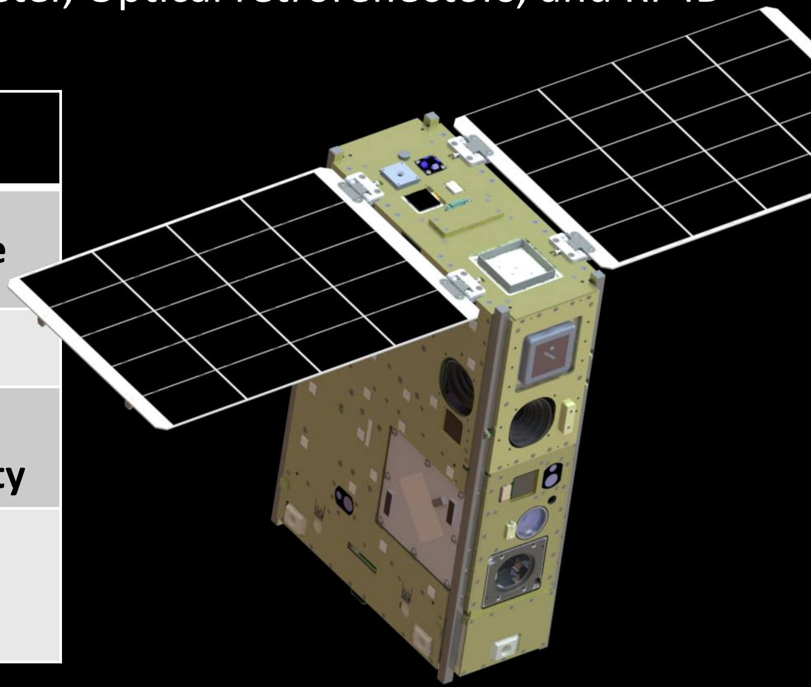
Mission Objectives

- PACE-2 is the second of NASA STMD-SST PACE Advanced Developments Projects (ADP) series developed at NASA ARC
- Develop and demonstrate a low-cost, rapid, reproducible PACE-ADP spacecraft platform to support payload maturation

  “Disrupt, Innovate, Experiment”
- Key Technologies: In-house developed Advanced Developments Projects (ADP) SC avionics, Payload suite: SEEKER In-space inspection payload, INTREPID gamma/neutron particle detector & spectrometer, Optical retroreflectors, and RF ID Tag

PACE-2 Key Parameters

Form Factor	# Spacecrafts	Orbit	Altitude (perigee/apogee)	Inclination	Launch Date
6U	1	LEO	525 km x 525 km	97.50° (SSO)	10/1/2022
Mass	**Dispenser or Interface**	**Mission Duration**	**Comm Licensing Status**	**Cost**	**Current Phase/Activity**
~10kg	Maverick Space 6U NLAS dispenser, Space-X T6 Falcon 9	8-11 mo.	NTIA – RFA Granted (Mod Req.)	$3.25M	C



PACE-2 Team Composition

Management	Principal Investigator	Project Manager	Mission Systems Engineer
Team Member Name	Sam Pedrotty	Anh N. Nguyen Jan Stupl (dPM)	Dayne Kemp
Organization	NASA JSC	NASA ARC	NASA ARC - Axient

PACE-2 Payload & Bus	Payload #1	Payload #2	Payload #3	Spacecraft Bus
Title/Acronym	SEEKER In-space Inspector	INTREPID Particle Detector	RF ID Tag	PACE-ADP (Advanced Developments Projects)
Organization	NASA JSC	NASA ARC	Stellar Exploration	NASA ARC

Data Systems	Mission Operations Center	Payload Operations Center	Ground Station/Network	Data Repository
Title/Acronym	PACE-ADP	PACE-ADP	PACE-ADP	PACE-ADP
Organization	NASA ARC	NASA ARC	AWS S-band), PACE Long Range (LoRa), GlobalStar, Iridium	NASA ARC


PACE-ADP PL Vol. (yellow), Bus Vol. (red)
PACE-2 INTREPID Payload
PACE-2 SEEKER Payload
PACE-ADP Mission Ops
PACE LoRa GS
PACE-ADP Avionics
PACE-1 LIFO
PACE-1 Art Install
PACE-1 Mission Sim
PACE-1 Development
PACE-1
Photo Credit: NASA/Dominic Hart

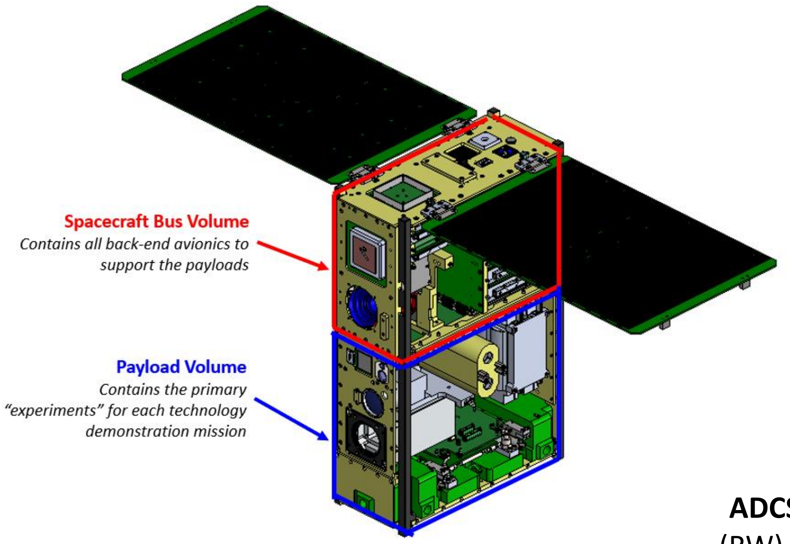
PACE-2 Key Components

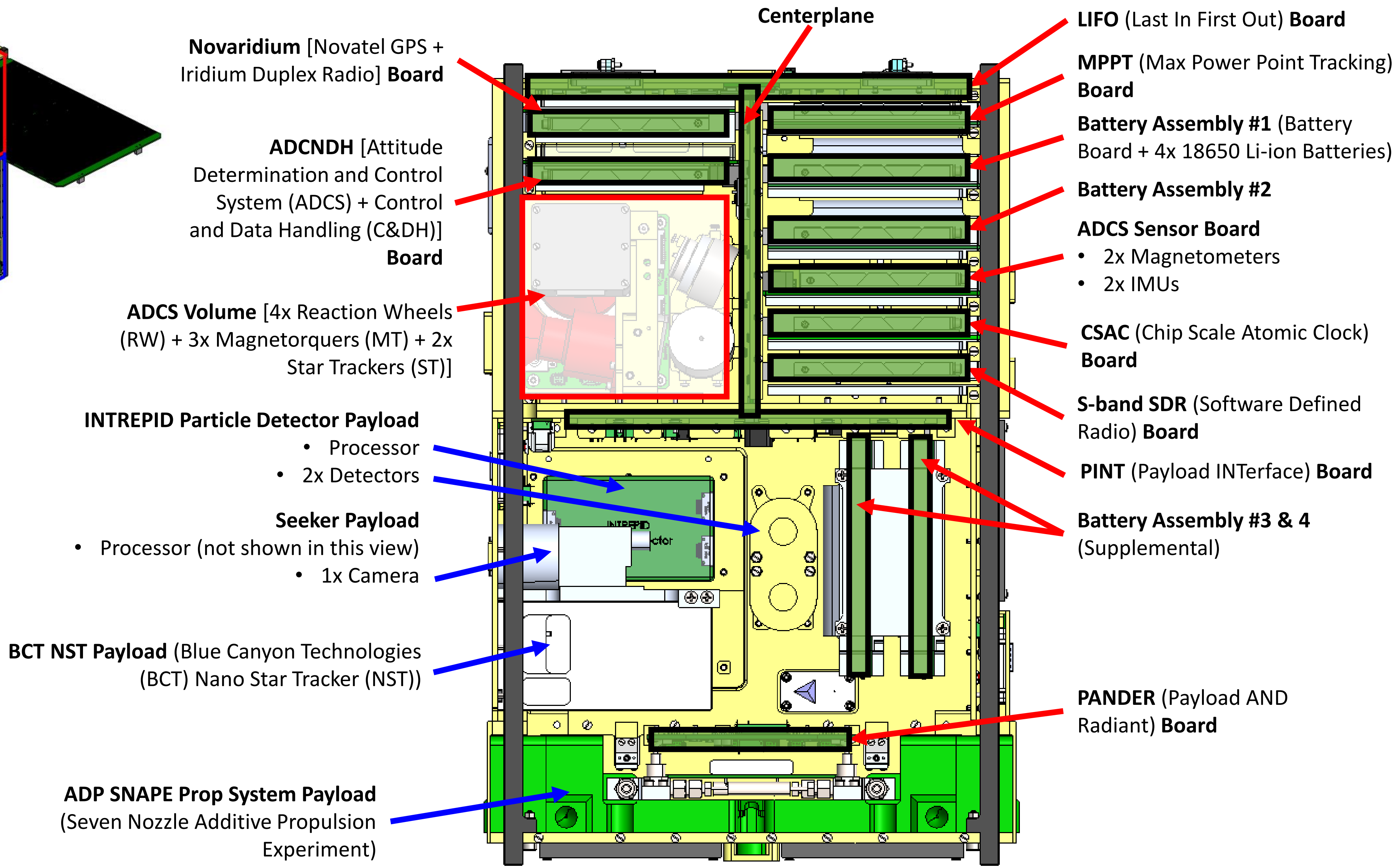
The PACE-2 Spacecraft is developed in-house using commercial-off-the-shelf (COTS) components

Subsystem	Description	Key COTS Components
Bus C&DH		
Main Processor	PACE-ADP custom in-house FSW; low-level FSW development appropriate for nanosatellite architectures	Vorago VA10820 ProAsic3 FPGA, ZYNQ SoC 7000 series
Data Storage	• 256KB Critical Data (2x) • 128MB Non-Critical Data (2x) • 8GB Backup/Payload Data (2x)	Cypress 2-Mbit (256K x 8) Serial (SPI) F-FRAM; Apacer 4GB Industrial MicroSD (SLC NAND) AP-MSD04GIHI-T; Micron Technology Inc. 8Gb FLASH – NAND MT29F8G08ABACAWP-IT:C
Bus Comm		
Radio	PACE-ADP custom S-band SDR and LoRa Radios Uplink 500 kbps (S-band), Downlink 1 Mbps (S-band)	LoRa: ADP-MAA-0604-014; S-Band: Artix-7 FPGA + AD9361_TQL9044; Iridium 9603; GlobalStar STX3
Antenna	PACE-ADP custom S-Band Patch (2x), LoRa Patch (1x), SkyTraq GPS + GlobalStar (1x), NovAtel GPS + Iridium Patch (1x)	All PACE Custom
Bus Power		
EPS	PACE-ADP in-house design w/ nominal 3.3V Bus voltage	TI BQ24650 MPPT battery charger ICs
Batteries	PACE-ADP in-house design & build w/ 16x 18650 Li-ion Batteries 56Wh (Nominal Energy) 656W (Absolute Peak)	LG Li-ion INR18650 MJ1 3500mAh Batteries
Solar Array	PACE-ADP in-house design & build w/ 5S4P deployable arrays (~12V, 500mA per string). 2x 6U Panels; Solar Array Peak Power 47 W (BOL)	SpectroLab XTE-SF 32% efficiency

PACE-2 Key Components

Subsystem	Description	Key COTS Components
Bus GN&C		
Reaction Wheels	PACE-ADP in-house design & assembly utilizing COTS Motor	Maxon #351099 Motors
Magnetorquers	PACE-ADP in-house design & wind	Various COTS parts
Star Tracker	PACE-ADP in-house design utilizing 1.3 Megapixel 150 FPS Global Shutter CMOS Image Sensor	Onsemi NOIV2SN1300A-QDC
Fine Sun Sensor	PACE-ADP Pyramid and Quad FSS	OSRAM SFH 2430-Z, First Sensor QP50-6-SM
Inertial measurement unit (IMU)	Small form factor 6 degrees of freedom IMU: triaxial angular rates and linear accelerations, high-stability and high-precision measurement capabilities with the use of high-precision compensation technology	EPSON M-G370PD
Propulsion		
Thruster	PACE-ADP in-house design & build: 7 nozzles, 3 DOF ACS + 7 m/s dV, 78.5 N-s total impulse, 200g R-236fa. BioSentinel & Starling GaTech design	Somos Perform 3D Printed Tank
SEEKER Payload		
Optics	USB3.1 industrial 2.3MP B/W camera, USB3 micro-B - SONY IMX174LLJ-C, B/W, global shutter, CMOS	Ximea MC023MG-SY-UB;
Processor	~2GHz, 64-bit Intel ATOM and a Intel Gen 8 HD 400 GPU	UP Board Series with Intel® Atom™


Spacecraft Bus Volume
Contains all back-end avionics to support the payloads
Payload Volume
Contains the primary "experiments" for each technology demonstration mission


Centerplane
Novaridium [Novatel GPS + Iridium Duplex Radio] Board
ADCNDH [Attitude Determination and Control System (ADCS) + Control and Data Handling (C&DH)] Board
ADCS Volume [4x Reaction Wheels (RW) + 3x Magnetorquers (MT) + 2x Star Trackers (ST)]
INTREPID Particle Detector Payload
• Processor
• 2x Detectors
Seeker Payload
• Processor (not shown in this view)
• 1x Camera
BCT NST Payload (Blue Canyon Technologies (BCT) Nano Star Tracker (NST))
ADP SNAPE Prop System Payload (Seven Nozzle Additive Propulsion Experiment)
LIFO (Last In First Out) Board
MPPT (Max Power Point Tracking) Board
Battery Assembly #1 (Battery Board + 4x 18650 Li-ion Batteries)
Battery Assembly #2
ADCS Sensor Board
• 2x Magnetometers
• 2x IMUs
CSAC (Chip Scale Atomic Clock) Board
S-band SDR (Software Defined Radio) Board
PINT (Payload INTerface) Board
Battery Assembly #3 & 4 (Supplemental)
PANDER (Payload AND Radiant) Board

PACE-2 Risks & Mitigations

Top 3 Risks

#	Short Risk Description	Risk Description	Mitigation Approach
1	**COVID-related supply chain shortages**	Given the COVID-related supply chain shortage and obsoletion of parts, there is a high likelihood that critical items are delayed or no longer available leading to schedule delays	Break off processors into daughter cards that will attach to the larger boards. Stock high-demand ICs
2	**Staffing turnover**	Given the locality of NASA ARC in silicon valley, there is a medium likelihood that staff will leave the project to pursue work outside of the organization	Continuously interview and hire. Ensure staff are engaged with the project and goals are aligned.
3	**Tech Demo Platform**	Given the PACE spacecraft is a rapid, low-cost, tech demo platform, there is a likelihood that PACE-2 will not meet all technical baseline requirements as intended.	Select COTS based parts with heritage or environmental parameters that are suited for the space environment. Design with best engineering practices. Test-as-you-fly as much as possible

PACE Issues

Top Issue: Balance of cost, schedule, risk

Challenge	Trade	Cost	Balance
Cost	Utilize lower-cost COTS Parts	Increased technical risk from non-heritage system	Careful selection of parts & best engineering practices
Schedule	Decrease amount testing or descope options	Increased technical risk, potential to not meet requirements	Minimum compressed schedule, launch slip, test on-orbit, solid requirements
Staffing	Fast & lean team vs large project team	Labor costs, having part-time staff, staff turnover risks	Engage staff with interesting & exciting work; Team

PACE-1 Lessons Learned

Top 3 Lessons Learned

	What happened?	What did we learn from it?	Proposed Mitigation Strategies
1	Never heard from PACE-1	• Helium purge could have contributed to unknown spacecraft behavior • Test-as-you fly vs Test-on-orbit • Outcome is acceptable as part of project risk posture • Iterative SC series allows fixes to potential issues	• Ride at the front-end of the stack if funds permit • Helium purge spacecraft as part of environmental test campaign • Careful selection of parts or ops strategies
2	Tracking SC with anomalies very difficult	• Early tracking is very difficult on rideshare launches when SC is silent • Ground-based infrastructure and development are required to utilize RF ID Tags • Optical Tags require tracking before lasing • Process of elimination for identification	• Utilize satellite-to-satellite communications whenever possible • Work closely with RF ID tag supplier and ground-segment
3	RFA Issued Late	• Some LV acceptable of Stage 2 Cert before RF Authorization to integrate • Program to accept risk of deployment after integration in the event of RFA not issued	• Apply licensing as early as possible • Work with launch service provider and spectrum office closely