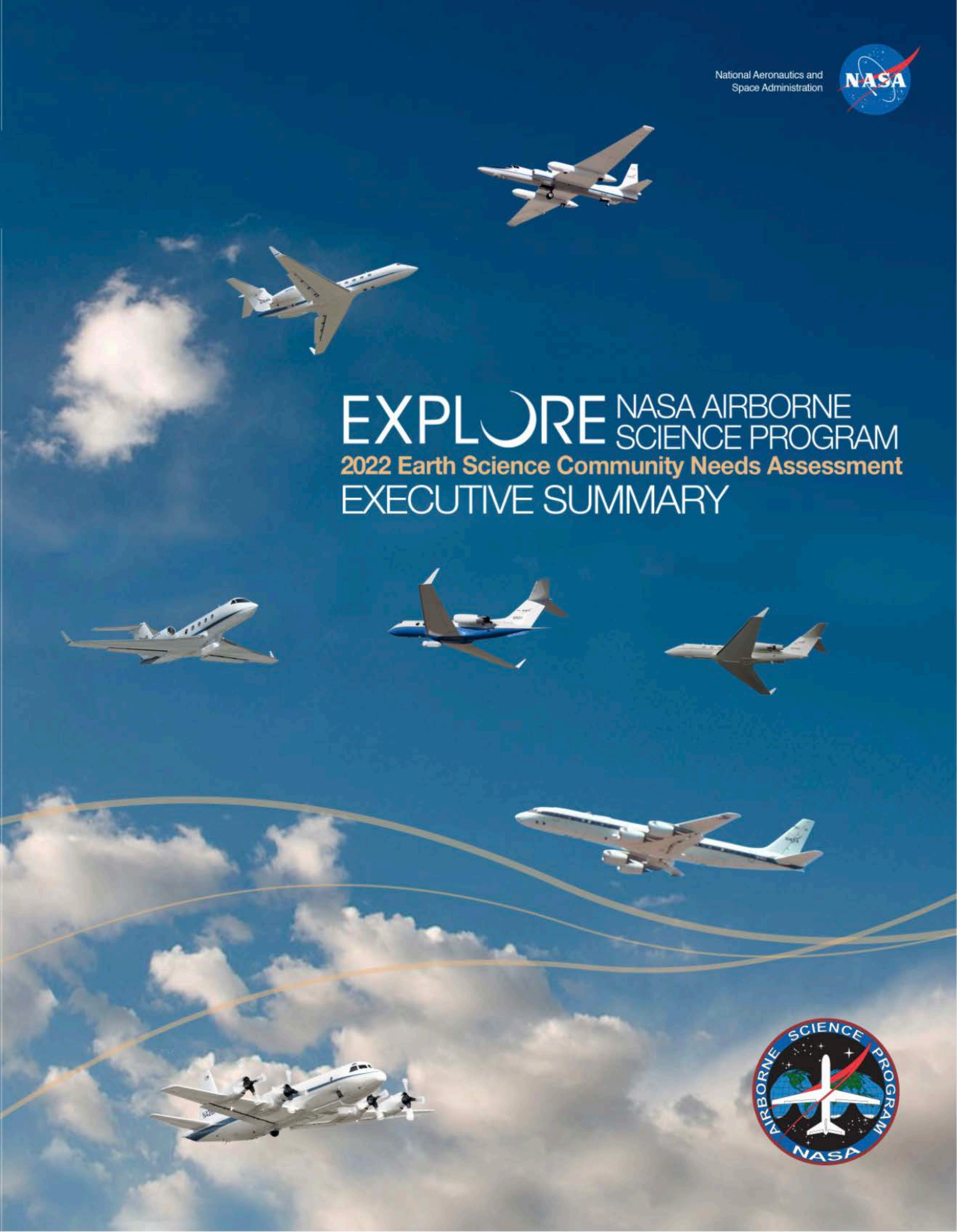
National Aeronautics and
Space Administration



EXPLORE NASA AIRBORNE SCIENCE PROGRAM

2022 Earth Science Community Needs Assessment

EXECUTIVE SUMMARY

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The primary objective of the NASA Airborne Science Program (ASP), managed under the Science Mission Directorate Earth Science Division, is to meet the needs of the NASA Earth Science community with respect to in situ atmosphere or remotely sensed sub-orbital measurements. Program objectives are driven primarily by Research and Analysis (R&A) Program-funded projects that use airborne instruments in support of satellite calibration, algorithm or model validation, or multi-instrument, multi-vehicle missions to understand fundamental earth system processes. Prior to launch, many flight project develop airborne instruments that simulate intended measurements from orbit.

This analysis of Program stakeholder needs is conducted approximately every 5 years and is the third internal ASP report to assess changing needs within the NASA science community. The intent of this report is to summarize the NASA Programs, Missions, and Projects for which there are clear requirements for airborne platforms, as well as documenting stated needs, or interest, from future stakeholders.

Requirements for airborne observations originate from the following NASA Earth Science activities:

- **NASA Earth observing satellite missions,**
- **Earth Science R&A data collections and field studies,**
- **Earth Science instrument / technology development**

Data for this report have been collected through several means over the past 2 years and validated where possible by Program Managers and Program Scientists at NASA HQ.

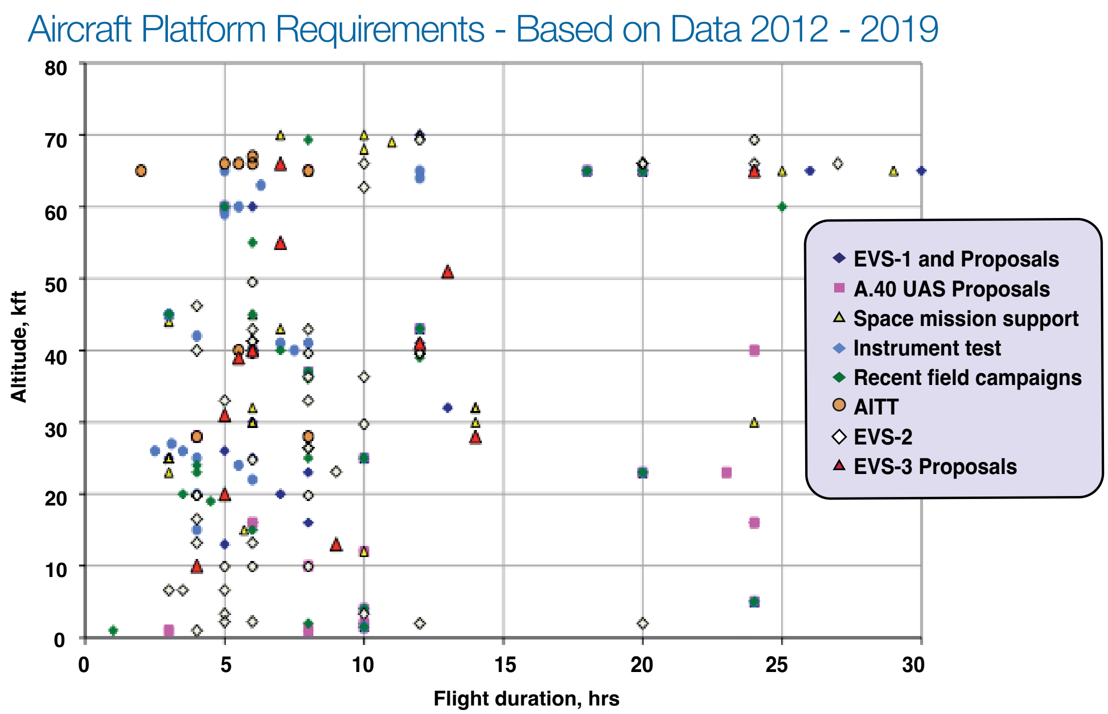
Sources of information include but are not limited to:

- Interviews with Program Scientists through the annual ASP 5-yr planning exercise
- A survey completed by principal investigators at the NASA Centers,
- Reviews of science mission planning documents,
- Requests for NASA ESD flight hours in the NASA Science Operations Flight Request System (SOFRS)
- Participation in science team meetings and community workshops
- Requests and early planning for Designated Observables and Targeted Observable missions, as defined by the NRC 2017 Decadal Survey.

The fleet of available aircraft spans several orders of magnitude in terms of available payload mass, provides measurements from the surface to 70,000ft, and has flight ranges that exceed 5000 nautical miles. This owes to the variety of different vantage points required, payload mass, range, duration and cost. The following table indicates the characteristics of the NASA aircraft in altitude, endurance, range, and payload capability.

Airborne Science Aircraft and their characteristics

Platform Name	Center	Payload Accommodations	Duration (Hours)	Useful Payload (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)
ASP Supported Aircraft							
DC-8	NASA-AFRC	4 nadir ports, 1 zenith port, 14 additional view ports	12	50,000	41,000	450	5,400
ER-2 (2)	NASA-AFRC	Q-bay (2 nadir ports), nose (1 nadir port), wing pods (4 nadir, 3 zenith ports), centerline pod (1 nadir port)	12	2,900	>70.000	410	5,000
G-III/C-20A	NASA-AFRC	UAVSAR pod	7	2,610	45,000	460	3,000
G-III	NASA-JSC	UAVSAR pod, Sonobuoy launch tube	7	2,610	45,000	460	3,000
G-III	NASA-LaRC	2 nadir ports	7	2,610	45,000	460	3,000
GV	NASA-JSC	2 nadir ports	12	8,000	51,000	500	5,500
P-3	NASA-WFF	1 large and 3 small zenith ports, 3 fuselage nadir ports, 4 P-3 aircraft window ports, 3 DC-8 aircraft window ports, nose radome, aft tailcone, 10 wing mounting points, dropsonde capable	14	14,700	32,000	400	3,800
WB-57	NASA-JSC	Nose cone, 12 ft of pallets for either 3 ft or 6 ft pallets, 2 Spearpods, 2 Superpods, 14 Wing Hatch Panels	6.5	8,800	>60,000	410	2,500
Other NASA Aircraft							
B-200 (UC-12B)	NASA-LaRC	2 nadir ports, 1 nose port, aft pressure dome with dropsonde tube, cargo door	6.2	4,100	31,000	260	1,250
B-200	NASA-AFRC	2 nadir ports	6	1,850	30,000	272	1,490
B-200	NASA-LaRC	2 nadir ports, wing tip pylons, zenith site for aerosol inlet, lateral ports	6.2	4,100	35,000	275	1,250
C-130	NASA-WFF	3 nadir ports, 1 zenith port, 2 rectangular windows, wing mount for instrument canisters, dropsonde capable, cargo carrying capable	10	36,500	33,000	290	3,200
Cessna 206H	NASA-WFF	Wing pod, belly pod, modified rear window for zenith ports	5.7	1,175	15,700	150	700
Dragon Eye (UAS)	NASA-ARC	*In situ* sampling ports	1	1	>500	34	3
HU-25A Guardian	NASA-LaRC	1 nadir port, wing hard points, crown probes	6	3,000	42,000	430	2,075
Matrice 600 (UAS)	NASA-ARC	Imager gimbal	1	6	8,000	35	3
SIERRA-B (UAS)	NASA-ARC	Interchangeable nose pod for remote sensing and sampling, 1 nadir port	10	100	12,000	60	600
WB-57 (2)	NASA-JSC	Nose cone, 12ft of pallets for either 3ft or 6ft pallets, 2 Spearpods, 2 Superpods, 14 Wing Hatch Panels	6.5	8,800	60,000+	410	2,500



Aircraft performance specifications based on proposal requests

The chart above, based upon aircraft support requested in recent solicitations, provides a useful way to represent the broad set of science needs across Earth Science disciplines. It also reflects what aircraft are currently available and able to carry a given mass of payload while also demonstrating a sustained need for high altitude, medium altitude, and low altitude flight.

The series of tables below summarize how aircraft are being used or planned for use in support of NASA Earth Science Division satellite programs, including the types of instruments, current examples of airborne instruments, as well as the class of aircraft that is required. For future missions the aircraft represent various general capabilities such as heavy lift, high or low altitude, and are also based on past trends in given communities. Calibration and Validation refers to the under-flight of satellites with well calibrated airborne instruments so as to assess the quality of the space instrument as it degrades over time, and to provide high resolution data that can be used to validate that data products produced by space mission processing algorithms yield scientifically and socially useful data products. These algorithms and how they process the data are based on assumptions made by satellite simulation through airborne observations.

Airborne Science support for NASA Earth Science Space Missions in Extended and Primary Operations (active missions) is summarized in the table on the following page. The supporting aircraft have the capability to carry the supporting instrument and perform the supporting activities.

Airborne Science support for NASA Earth Science Space Missions in Extended and Primary Operations (active missions).

Mission	POC	Satellite Instruments	Supporting/ related aircraft instruments	Airborne Science supporting activities	Supporting Aircraft
Aura	Jucks	MLS, HIRDLS, OMI, TES	ASMLS; Discover-AQ, KORUS-AQ packages	Data product validation	ER-2, P-3, DC-8
Calipso Cloudsat	Considine	CALIOP, IIR, WFC, CPR	HSRL, HSRL-2, AMPR, CRS, CPL	Cal/val	B-200, UC-12, ER-2
Aqua / Terra	Jucks	MODIS, AMSR-E, ASTER, MISR, CERES	MAS, eMAS, MASTER, AVIRIS	Data product Validation	ER-2, Twin Otter
GPM / Aeolus	McCarty	Microwave Imager, Doppler Precipitation Radar (DPR)	AMPR, COSMIR, HIWRAP	Instrument calibration & Data product validation	ER-2, DC-8, Citation
Suomi-NPP	Lorenzoni	VIIRS, CrIS, ATMS, OMPS	NAST, S-HIS, eMAS, MASTER, AVIRIS	Instrument calibration & Data Product validation	P-3, Twin Otter, ER-2
SMAP	Entin	L-band radar, L-band radiometer	UAVSAR, PALS, SLAP	Instrument calibration & Data Product validation	G-III, P-3, B-200, DC-3
ICESat-2	Markus	5-beam laser mapper	LVIS, Ice Bridge suite	Instrument calibration & Data Product validation	G-V, P-3, DC-8
Landsat - 9	Margolis	Multi-spectral imager	AVIRIS-NG, AVIRIS classic, MASTER	Data Product validation	ER-2, B-200
ECOSTRESS (ISS)	Turner	High resolution multispectral thermal imaging spectrometer	HYTES, AVIRIS-ng	Data Product validation	B-200, ER-2, G-V
GEDI (ISS)	Margolis	Lidar	LVIS, G-LiHT	Data product validation	B-200, G-V, various

The tables below represent currently planned needs for aircraft support to missions in various stages of formulation and development:

Summary of Missions in Implementation and Pre-formulation Phases (Future)

Mission / (launch date) / POC	POC	Spacecraft Instruments	Supporting/ related aircraft instruments	Airborne Science supporting activities	Representative Supporting Aircraft
NISAR (2024)	Bawden	L-band SAR, S-band SAR	UAVSAR, ASAR	Algorithm development, Instrument calibration & Data product validation	G-III
PACE (2024)	Lorenzoni	Ocean Color Instrument (OCI); Polarimeter	OCI simulator, PRISM, HSRL	Algorithm development, Instrument calibration & Data Product validation	B-200, ER-2, G-III (PRISM)
SWOT (2022)	Shiffer	Ka-band radar, C-band radar	AirSWOT, MASS, DopplerScatt	Algorithm development, Instrument calibration & Data Product validation	G-V, B-200
TEMPO (2023)	Lefer	Geostationary ultraviolet visible spectrometer	GEO-TASO, GCAS	Instrument calibration & Data Product validation	UC-12, B-200
MAIA (2024)	ESTO, Maring	Air pollution particulate using twin camera radiometer and polarimeter	Air quality package	Instrument calibration & Data Product validation	ER-2, DC-8
TROPICS (2022)	ESTO	Microwave radiometers (3)	AMPR, HAMSR	Data product validation	DC-8, ER-2
GEOCARB (2024)	Jucks	Spectrometer	Picarro, CO_2/CH_4	Data product validation	Alphajet, profiling UAS
GLIMR (2026)	ESTO/ Entin, Lorenzoni	Hyperspectral imager	AVIRIS-ng, HyTES, PRISM	Instrument calibration & Data Product validation	G-III, G-V, B-200

Airborne Support to Designated Observables Missions

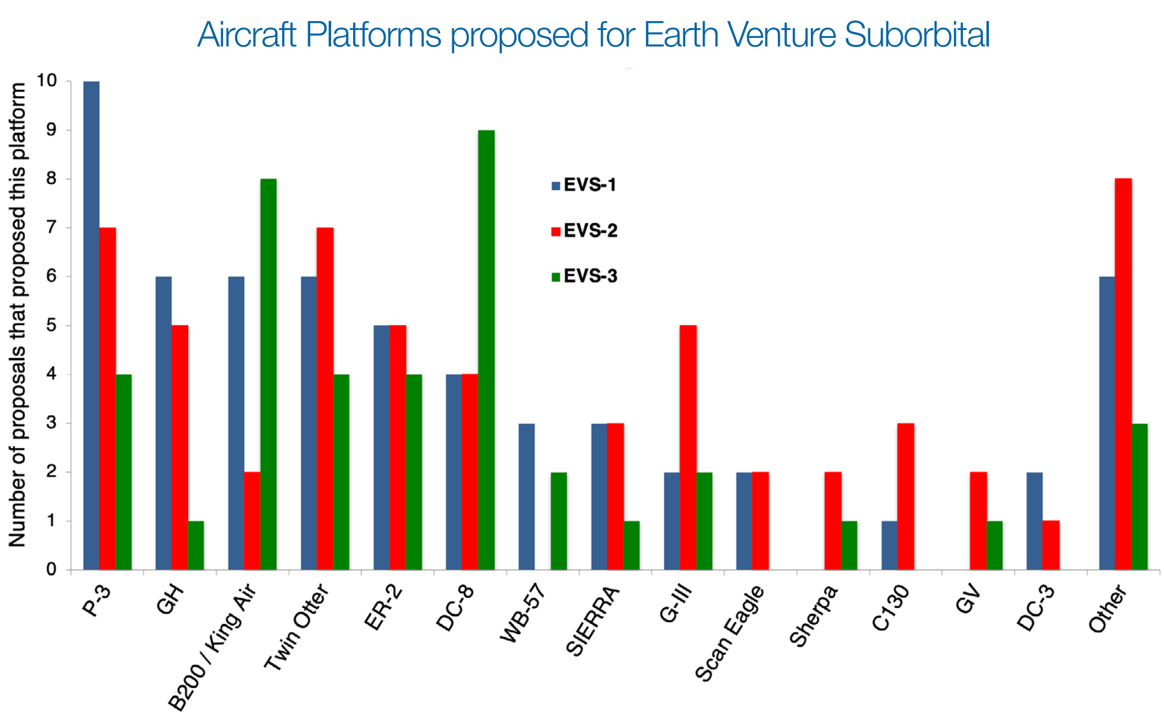
Mission	POC	Spacecraft measurement or Instruments	Supporting/ related aircraft instruments	Airborne Science supporting activities	Possible Aircraft
AOS	Maring	Lidar, radar, polarimeter, radiometer	Polarimeter, radiometer, lidar, radar	Algorithm development, Instrument calibration & Data product validation; **Suborbital component currently being defined.**	ER-2, DC-8
SBG	Turner	Hyperspectral visible, short-wave and thermal IR spectrometer (or) spectrometers	PRISM, HYTES, AVIRIS-ng, MASTER	Precursor data collection; Instrument calibration; Data Product validation	ER-2, G-V, G-III; commercial B-200
SDC	Bawden	Interferometric SAR	UAVSAR in multiple frequencies	Instrument calibration & Data Product validation	G-III, G-V

Upcoming field campaigns and process studies are summarized in the table below. For most of these missions the aircraft have been specified or indicated. This demonstrates a current and sustained need for the currently available aircraft while also showing sustained support for Commercial Aviation Services (CAS), especially for single instrument projects.

Upcoming Field Campaigns

Mission/ POC	Objective	Location	Date	Aircraft Instrumentation	Aircraft
ACCLIP / Maring, Jucks	Air pollution monitoring	Korea	2022	Similar to Korus-AQ package	WB-57
ABoVE / Margolis	Boreal land composition changes	Alaska, Canada	2022-23	UAVSAR, AVIRIS-ng, LVIS	G-III, B-200, G-V
SnowEx / Entin	Snow-water equivalent under various conditions	Colorado, Alaska	2022	UAVSAR	G-III
CPEX-CV / McCarty/Maring	Microphysics and deep convection	Cape Verde, Africa	2022	DAWN, APR-3, HALO, dropsondes	DC-8
BioScape / Turner	Vegetation biodiversity	South Africa	2024	HyTES, AVIRIS-ng, PRISM, LVIS	G-III (L), GV
Terrestrial ecology and earth surface topography / Bawden, Margolis	L-band SAR for solid earth and vegetation measurements	North America	Ongoing	UAVSAR	G-III
STAQS / Lefer	Air quality measurements	CA, New York	2023	GCAS, HSRL-2 AVIRIS-NG, HALO	GV, G-III
ARCSIX / Maring	Radiation and chemistry	Arctic	2024	Spectrometer, radiometer, aerosol counter, LVIS	GV, P-3
Asia-AQ / Lefer	Air quality measurements	4 Sites in SE Asia	2024	Similar to Korus-AQ package for air pollution	GV, DC-8
Africa-AQ / Lefer	Air pollution monitoring	Africa	TBD	Similar to Asia-AQ package	GV, DC-8
BLUEFLUX / Hibbard	Carbon Monitoring	Florida	2022,2023, 2024	Picarro	B-200
AEROMMA / Lefer	Air Quality	CA, NYC, OH	2023	Payload similar to FIREX-AQ	DC-8
PACE PAX / Lorenzoni	PACE cal/val	California coast	Fall 2024	eMAS; PRISM, AirHARP, SPEX Airborne, HSRL-2, RSP	ER-2
Arctic COLORS / Lorenzoni	Coastal impacts of climate change	Alaska	TBD	Imagery, aerosols (like SABOR); PRISM	Low-to-mid altitude with moderate payload; UAS measurements

The Earth Venture Suborbital series of missions have pushed the boundaries of knowledge in many science disciplines by flying a series of multi-year flights using a variety of platforms to improve process models and forecasts. Data from more than a decade of proposals shows sustained needs for the current fleet, while also emphasizing that both the “B-200” and “Other” categories (consisting largely of CAS) are needed at approximately the same magnitude. Some trends in science needs from the EVS-3 proposals include continued scientific interest in polar regions (Arctic, Greenland, Alaska, Antarctic), continued strong interest in weather and atmospheric composition and chemistry, and increased use of multi-platform campaigns; more than half of the mission concepts proposed call for multiple aircraft, some in stacked formation.



Aircraft requested for Earth Venture Suborbital missions

While CAS are often used for initial testing of new instrument concepts, many instrument teams continue to seek out the ER-2 for the ability to carry larger instruments above 95% of the atmosphere to simulate space-like observations. The table below provides a current snap shot of instruments scheduled for test flight. The Earth Science Techology Office (ESTO) Program is accelerating the pace of funding for the Instrument Incubator Program so this level of need is likely to continue and possibly grow.

Instrument flight requests

Instrument	PI	Aircraft	Year
CAMLS / A-SMLS	Livesey	ER-2	2022
SHOW	Bourassa	ER-2	2022
AirMSPI-2	Diner	ER-2	2022
eMAS / PICARD validation	Jacobson	ER-2	2022
SoOpSAR	Yueh	TOIL	2022
GNSS RO/SF	JPL	B-200	2022
Air-MASTER	Sanchez- Barbetty	DC-8	2022
3D Cloud Scanner	Martins	ER-2	2022
Radar sounder	Cahill	P-3	2022
CHAPS Demonstrator	Schwartz	B-200	2022/23
Aerosol Wind Profiler	Marketon	G-III (LaRC)	2022
CoSSIR	Adams	ER-2	2022
KU Multi-channel snow radar	Paden	P-3	2022

CONCLUSIONS

Across all Earth science stakeholders who were contacted during this survey, there exists a strong, continued need for NASA Science aircraft. New satellites under development have a variety of airborne instruments that are or will soon be used to develop new data products, and the Earth Venture Suborbital Program and Research and Analysis Programs represent a sustained need for the core aircraft

The Program will continue to fly UAVSAR (or an updated SAR payload) for NISAR validation, indicating sustained need for business class jets such as the G-III and GV. Both SWOT and PACE will make use of airborne measurements for calibration and validation using a variety of active and passive optical instruments.

The Designated Observables satellite missions recommended by the National Academies have significant need for aircraft both for technology development and algorithm refinement for data products. AOS has a defined suborbital team to plan their use of aircraft and SBG has been building a long-term time series through the Western Diversity Time Series to refine imaging spectroscopy.

Missions in the technology incubator category, including STV and PBL, have expressed a need for instrument development using aircraft in addition to needing aircraft measurements for calibration, similar to OIB for ICESAT, or LVIS for GEDI.

With increased cadence of the instrument incubator program we see sustained need for ER-2 and CAS for instrument testing and maturation.

ER-2 continues to be important for technology development (Table, pg 8), process studies, and satellite support. Delays of several years for short instrument test flights are becoming more common because of maintenance delays. The Program should consider funding operations for 2 concurrent aircraft. This could be accomplished through contracts to LM or hiring additional mechanics and pilots at AFRC.

CAS continue to provide support for light aircraft with medium range requirements and this requirement is stable to growing, but largely reflects continued interest in AVIRIS-NG.

Following is a summary of the major survey and discussion input comments from our visits with NASA Center scientists.

Aircraft:

All currently ASP-supported aircraft are in routine use and continued use is projected and desired.

Gaps in the fleet include:

- Aircraft capable of supporting large instruments needing access to doors or large ports. Aircraft with suitable capability, used in the past, have included Twin Otter, DC-3/Basler, and Sherpa.
- Storm-penetrating aircraft for observing processes in severe storms, fire and volcanic plumes.
- Concerns were voiced about the availability of the ER-2 and G-V. Suggestions of having another GV dedicated to science and going back to 2 concurrently operational ER-2s.
- King Air 350ER or inexpensive aircraft with longer range and more schedule availability than LARC/AFRC B-200; although not a gap in the fleet, the cost of the currently un-supported B-200s is too expensive.

Aircraft accommodations or payload support needed:

- Strong need for dropsonde capability from long-range aircraft, e.g., G-V
- Aircraft modifications or aircraft with two nadir ports AND radar support
- Zenith port(s) on the G-V (or other)
- Forward and nadir cameras on ER-2 with real-time data downlink
- A new, advanced replacement for UAVSAR and its 3 frequency versions.

Other:

- Real-time data is desired for many instruments
- Suggestion to make AirSWOT a facility instrument
- Single-pass interferometry in demand – how to modify a/c to do this?
- Suggestion by JPL researchers to rotate P-3 and Sherpa to West Coast