NEW MILLENIUM PROGRAM

Serving Earth and Space Sciences

Fuk Li
Jet Propulsion Laboratory
California Institute of Technology

March 18, 1999
Ambitious Plans

Office of Earth Science
- EOS Post 2002
- LandSat Follow-on
- NPOES
- Advanced Geostationary
- ESSP

Office of Space Sciences
- Mars Exploration
- Outer Planets
- Discovery
- Solar Terrestrial Probes
- UNEX/SMEX/MIDEX
- Gravity Probe B/LISA
- Next Generation Space Telescope
- Space interferometry Mission/Terrestrial Planet Finder
Advanced Technologies: Essential to Achieve OES and OSS Objectives

Science Missions

Impediments to Rapid Technology Infusion:
- Lack of flight heritage
  - real or perceived risks
    - cost
    - schedule
    - performance
- Little visibility to mission planners
  - capabilities poorly understood
  - A complete paradigm shift is needed to fully exploit some technologies
Cross-Enterprise Technology Thrust Areas

Office of Earth Science
The New Millennium Program

A cross-Enterprise program to identify and flight validate breakthrough technologies that will significantly benefit future Space Science and Earth Science missions

- Breakthrough technologies
  - Enable new capabilities to meet Earth and Space Science needs
  - Reduce costs of future missions

- Flight validation
  - mitigates risks to first users
  - enables rapid technology infusion into future missions
Common Processes for Earth & Space Sciences Programs

- Identification of Needs
- Identification of Tech.
- Project Formulation
- Technology Selection
- Project Implementation & Tech Validation
- Technology Infusion

Needs & Opportunities
Flight Project Formulation Process

Preliminary Project

Concepts
Validation Flights Launch Schedule

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Deep Space One: Asteroid Flyby

- Validate Technologies for Rapid Access in Deep Space Exploration

- Advanced Solar Concentrator Array
  Able Engineering Inc., BMDO, Entech, JPL, Lewis Research Center, & Tecestar

- Miniature Integrated Camera Spectrometer
  Boston U., JPL, Rockwell, SSG Inc., USGS, & U of AZ

- Autonomy Remote Agent Architecture
  Ames Research Center, Carnegie Mellon U & JPL

- Autonomous Onboard Optical Navigation
  JPL

- NSTAR Ion Propulsion System
  Hughes, JPL, Lewis Research Center, MSFC, Moog Inc., Physical Science & Spectrum Astro

- Multifunctional Structures
  Air Force Phillips Lab & Lockheed Martin

- Spacecraft
  Spectrum Astro, JPL

- Small Deep Space Transponder
  JPL & Motorola

- Ka-Band Solid State Power Amplifier
  Lockheed Martin

- Plasma Experiment for Planetary Exploration
  SwRI & Los Alamos National Lab
## DS1 Technologies and Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Potential Earth Science Application/Benefit</th>
<th>Potential Space Science Application/Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Propulsion Engine</td>
<td>save a factor of 2-3 in flight time while significantly increasing launch margin</td>
<td>station keeping</td>
<td>primary propulsion &amp; station keeping</td>
</tr>
<tr>
<td>Solar Concentrator Array</td>
<td>provides a 7:1 solar concentration factor, offers significant array cost reduction due to the reduced (1/7) quantity of cells</td>
<td>power generation</td>
<td>power generation</td>
</tr>
<tr>
<td>Ka-band Solid State Power Amplifier</td>
<td>most efficient (13%), highest power (2.6 W), space qualified</td>
<td>high band communication and freq. alternative</td>
<td>high performance com</td>
</tr>
<tr>
<td>Deep Space Transponder</td>
<td>3 times mass reduction and single unit architecture</td>
<td>autonomous operations, event detection</td>
<td>small &amp; low mass communication</td>
</tr>
<tr>
<td>Remote Agent Experiment</td>
<td>provide faster response to in-flight situation (&lt;1min vs. 3 days), reduce mission dev. cost and operations cost (&gt;30%)</td>
<td>autonomous operation</td>
<td>autonomous operations, uncertainty handling</td>
</tr>
<tr>
<td>Beacon Monitor Operations</td>
<td>achieves large reduction in ops. staffing; reduces the loading on an already over constrained DSN</td>
<td>autonomous operation</td>
<td>autonomous operation</td>
</tr>
<tr>
<td>Autonomous navigation</td>
<td>greatly reduce tracking, save nav. staff by a factor of 2-3, &amp; enhance mission science</td>
<td>small camera/spectrometer</td>
<td>deep space navigation</td>
</tr>
<tr>
<td>Miniature Imaging Camera Spectrometer</td>
<td>SiC structure and optics will allow for alignment and focus of optics at ambient temp with no change for operation at cryogenic temps</td>
<td>small camera/spectrometer</td>
<td>small camera/spectrometer</td>
</tr>
<tr>
<td>Miniature Ion and Electron Spectrometer</td>
<td>3x reduction in mass, volume, &amp; telemetry over SOA</td>
<td>characterize the solar wind &amp; ions, &amp; magnetosphere</td>
<td>detection of ions &amp; electrons</td>
</tr>
<tr>
<td>Low Power Electronics Experiment</td>
<td>30x power reduction relative to current SOA ASICs</td>
<td>micro/nano spacecraft</td>
<td>micro/nano spacecraft</td>
</tr>
<tr>
<td>Power Actuation and Switching Module</td>
<td>1/4 the weight and 1/10 the power relative to current SOA</td>
<td>instrument &amp; spacecraft functions</td>
<td>instrument &amp; spacecraft functions</td>
</tr>
<tr>
<td>Multi-Functional Structures</td>
<td>5-10x reduction in mass and volume; offers the flex architecture to interconnect MCMs, MEMS sensors, and power subsystem</td>
<td>instrument &amp; spacecraft</td>
<td>instrument &amp; spacecraft</td>
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</table>
Earth Observer 1
Validation of 9 Breakthrough Technologies

X-Band Phased Array Antenna:
Boeing, GSFC & Lewis Research Center

Leisa Atmospheric Corrector:
GSFC

Advanced Land Imager:
MIT Lincoln Lab,
GSFC, Raytheon,
Santa Barbara Remote Sensing,
& Sensor Systems Group

Carbon-Carbon Radiator:
Air Force Research Lab,
Amoco Polymers, BF Goodrich,
GSFC, Langley Research Center,
Lockheed Martin, Naval Surface Warfare Center, & TRW

Spacecraft:
GSFC,
Litton,
SWALES

Wideband Advanced Recorder Processor:
GSFC, Litton,
MIT Lincoln Lab,
Swales, & TRW

Hyperion:
GSFC, & TRW

Lightweight Flexible Solar Array:
GSFC,
Lockheed Martin,
& Phillips Lab

Pulsed Plasma Thruster:
GSFC,
Lewis Research Center & PRIMEX

Enhanced Formation Flying
GSFC, JPL
# Earth Observer One

## Technologies & Applications

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<th>Technology</th>
<th>Description</th>
<th>Potential Earth Science Application/Benefit</th>
<th>Potential Space Science Application/Benefit</th>
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<tr>
<td>• Hyperspectral/Multispectral imaging spectrometer</td>
<td>• multi-spectral (10 bands), high spatial resolution (30m) in the visible and near infrared spectral range with the goal of 5% absolute radiometric accuracy</td>
<td>• precursor for the Landsat instrument</td>
<td>• applicable to space science multi-spectral remote sensing</td>
</tr>
<tr>
<td>• Hyperion instrument with advanced E-Beam Gratings</td>
<td>• E-beam lithography produces high efficiency convex gratings at very low cost</td>
<td>• possible replacement for multi-spectral (Landsat) imaging</td>
<td>• applicable to space science multi-spectral remote sensing</td>
</tr>
<tr>
<td>• Atmospheric Corrector</td>
<td>• low cost, bolt on instrument provides correction of land imaged data for atm absorption. Improves accuracy of land imaging product</td>
<td>• future Earth imaging missions (e.g. RESOURCE 21) is considering this tech.</td>
<td>• provide multi-spectral capability for deep space</td>
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<tr>
<td>• X-band Phased Array Low Cost Antenna Demo</td>
<td>• provides high gain downlinks while reducing the need for a mechanical gimbals</td>
<td>• baselined by future Earth science missions including EOS missions</td>
<td>• applicable to space science missions requiring X-band communication</td>
</tr>
<tr>
<td>• Enhanced Formation Flying</td>
<td>• synchronous science measurements on multiple spacecraft, weather &amp; land-imaging collection 8-16 times faster than current Landsat or TIROS</td>
<td>• highly probable for use by EOS, Magnetospheric Multi-scale &amp; Mag. Constellation missions</td>
<td></td>
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<tr>
<td>• Carbon-Carbon Radiator</td>
<td>• 30-50% mass savings w. thermal conductivity 10-500 W/m-K</td>
<td>• being considered by SBIRS, lo &amp; hi</td>
<td>• applicable to Solar Probe, Space Time- Midex</td>
</tr>
<tr>
<td>• Lightweight Solar Array (LSA)</td>
<td>• ≥100W/kg array, low storage volume, jitter free shockless deployment</td>
<td>• being considered by SBIR lo &amp; hi, Nat Polar-Orbiting Operational Env. Sat.</td>
<td>• being considered by NGST, ST5 &amp; other OSS missions</td>
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<tr>
<td>• Pulsed Plasma Thrusters (PPT)</td>
<td>• high specific impulse (900-1200 sec), very low impulse bits (10-1000uN-s) at low average power (&lt;1 to 100W).</td>
<td>• being considered by Constellation X</td>
<td>• cited by Midex and SMEX proposals</td>
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<tr>
<td>• Wideband Advanced Recorder/Processor</td>
<td>• &gt; 40Gbits of storage, data throughout is 5.5x that of Landsat 7. It is</td>
<td>• applicable to Earth science missions with high data rate requirements</td>
<td>• applicable to space science missions with high data rate requirements</td>
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Common Benefits of Processes

- Enhanced NASA's technology community through partnerships
  - Industry
  - Academia
  - Government Laboratories
- Infusions into future missions
  - Future projects using NMP validated technologies
  - Technology database for PI missions
    - New capabilities enable new opportunities
    - MIDEX/SMEX/Discovery/ESSP
Enhanced NASA's Technology Community through Partnerships
(NMP Flight Team & Technology Partners)
Solar Electric Propulsion Future Users

Benefits of Solar Electric Propulsion
- Transportation
- Formation Flying
- Station Keeping/Orbit Maintenance

Space Science

Earth Science

Electric Propulsion
- NSTAR Ion Propulsion
- EOI Pulsed Plasma Thruster
- ESSP
Hyper/Multi-Spectral Imagers & Spectrometers Future Users

Earth Science
- Potential replacement for multi-spectral Landsat imager
- Hyper-spectral imaging spectrometer provides new observational capabilities

- Planetary & solar plasma scientists have proposed to use copies of the PEPE instrument for future missions
- Validation of an all SiC optical instrument covering the FUV to SWIR will enable many new miniature, low-mass cameras and spectrometers

Space Science
- MICAS camera design will be proposed for Pluto Flyby mission
Micro-Nano Spacecraft's Future Users

Multifunctional structure

Carbon-carbon radiator

Wideband Advanced Recorder/Processor

DS1

EO1

DS2

Advanced Micro Controller

Small Deep Space Transponder

DS1

DS1

Low Power Electronics

Power switching module

Innovations that simplify design, fabrication, reduces mass & reduce resource requirements

Earth Science

- Potential for EOS Follow-On
- ESSP

Mars Micro missions
STP Magnetospheric Multiscale Mission
Discovery
UNEX/SMEX/MIDEX

Space Science
High Data Rate Future Users

Space Science
Mars '01

- Reduces mass, volume & mechanical complexity for high data rate missions
- Essential for high-bandwidth spectral imaging instrument and active instruments (radars/lidars)

Earth Science

Technology database for PI missions

- Advanced Land Imager

New capabilities enable new opportunities

MIDEX/SMEX/Discovery/ESSP

Technology Readiness Database for Discovery 1998

<table>
<thead>
<tr>
<th>System or Subsystem (from Level 2 WBS)</th>
<th>POC Name/Org</th>
<th>POC Phone</th>
<th>POC Email</th>
<th>Funding Source</th>
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<tr>
<td>Advanced Land Imager</td>
<td>Nick Speciale</td>
<td>(301)286-8704</td>
<td><a href="mailto:nspeciale@go99.gsfc.nasa.gov">nspeciale@go99.gsfc.nasa.gov</a></td>
<td>URL for Additional Information: <a href="http://eo1.gsfc.nasa.gov/">http://eo1.gsfc.nasa.gov/</a></td>
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<td>Technology Name and Supporting UPN or other</td>
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<tr>
<td>NMP EO-1 UPN: 246</td>
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Description of Technology:
The Advanced Land Imager (ALI) is the centerpiece of the New Millennium, Earth Orbit-1 mission. It will validate technologies contributing to the reduction in cost of future land imaging missions such as the Landsat series or Earth imaging missions. The ALI will provide multi-spectral (10 bands), high spatial resolution (300m) in the visible and near infrared spectral range (0.5 to 2.5 um) with the goal of 5% absolute radiometric accuracy. The EO-1 mission will fly in formation with Landsat 7 and collect more than 200 common scenes for comparison.

The ALI will be a factor of 4 less in mass and 5 less in power than the Landsat 7 Enhanced Thematic Mapper (ETM+). The flight validation of key ALI technologies should lead to dramatically reduced cost and complex Landsat type missions. Some of the key technologies are:

1. Silicon Carbide Optics which are extremely lightweight optics that are stable over a wide range of temperatures. The goal is to demonstrate how well the Silicon Carbide maintain stable performance in a space environment.

2. Wide field, high resolution reflective optics which provides a full Landsat scene swath width (185km) and resolution using a simple push broom design. This technique will enable much lower cost instrumentation for future Landsat missions through use of non-mechanical scanning and reduced instrument complexity.

3. Multi-spectral imaging capability, the modular focal plane assembly provides substantial mass and power savings over comparable mechanical scanning instruments through innovative electro-optical design. Additionally, an innovative on-board calibration system will enable better characterization of instrument performance during observations.

Applicability
The ALI is a pathfinder to higher performance and lower cost land imaging instruments which meet the demanding Earth Science Enterprises requirements for remote sensing applications.

Benefit to Earth Science Missions
The ALI technologies reducing the mass, power, complexity and cost of future earth imaging systems for the Earth Science Program. A fully operational ALI has potential for reducing the cost and size of future Landsat type instruments by a factor of four to five.

Development Status and Plans for Flight Readiness

<table>
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<tr>
<th>Technology Maturity</th>
<th>Description</th>
<th>Date (to be) Completed</th>
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<tr>
<td>Component and/or breadboard validation in relevant environment</td>
<td>The flight ALI is currently undergoing integration at Lincoln Labs. The flight telescope has been delivered and the flight focal plane will be delivered in the mid-June timeframe. Calibration will occur in the Aug to November 1998 timeframe.</td>
<td>Dec 1998</td>
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<tr>
<td>System/subsystem model or prototype demonstration in a relevant environment (ground or space)</td>
<td>The ALI will be launched on the EO-1</td>
<td>May 1999</td>
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<tr>
<td>System prototype demonstration in a space environment</td>
<td>The ALI technologies will be fully flight qualified after it has completed one year of operation in the space environment</td>
<td>May 2001</td>
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<tr>
<td>Actual system &quot;flight proven&quot; through successful mission operations</td>
<td>ALI science objectives will be fully met after ALI completes land imaging for an entire growing season</td>
<td>Sept 2001</td>
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Technology database for PI missions
- NSTAR Electric Propulsion

New capabilities enable new opportunities
MIDEX/SMEX/Discovery/ESSP

Technology Readiness Database for Discovery 1998

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<tr>
<th>System or Subsystem (from Level 2 WBS)</th>
<th>POC Name/Org: J. F. Stocky</th>
<th>POC Phone: (818) 354-5358</th>
<th>POC Email: <a href="mailto:john.stocky@gsfc.nasa.gov">john.stocky@gsfc.nasa.gov</a></th>
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<th>URL for Additional Information:</th>
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<td>NSTAR Solar Electric Propulsion UPNs: 242, 632, 839</td>
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Description of Technology:
NSTAR is a high-specific impulse solar electric propulsion system for deep space primary propulsion. The NSTAR system consists of five principal elements:
1. A 30-cm ion thruster capable of processing 83 kg at power levels between 500 W and 2,500 W and providing 95 mili-N of thrust and an Isp of 3,120 hr/sect hor at maximum power.
2. A power processing unit (PPU) capable of providing the necessary voltages and currents required by the ion thruster from an input power source providing between 80 V and 160 V. Each power processing unit can control two ion thrusters sequentially, but not simultaneously.
3. A digital control interface unit (DCIU) that provides the command and telemetry interface with the spacecraft, which controls the power processing units - establishing proper set points for each thruster level commanded by the spacecraft, and which controls the flow rates provided by the propellant storage and control system.
4. A propellant storage and control system (PSCS) that provides Xenon to the ion engine at the flow rates commanded by the DCIU for each thruster level.
5. A diagnostics measurement system to measure induced fields during ion thruster operation to help verify the performance of the ion propulsion system and to measure the effect of its operation on the space plasma near the spacecraft. The diagnostics system is not required for operational use of the ion propulsion system.

Applicability
The NSTAR engine is applicable to many deep space missions, and particularly valuable for missions to distant or high delta-v targets.

Benefit to Deep Space Missions
NSTAR provides significantly higher specific impulse than conventional chemical propulsion. This translates into a smaller mass of fuel required to accelerate a spacecraft to a given velocity. On missions to distant objects or trajectories requiring a large delta-v, where the fuel mass is a significant factor, a smaller fuel load at launch can mean a smaller, lower cost launch vehicle, or it can be traded for higher spacecraft velocity or a shorter cruise time to the target for a given launch vehicle capacity.

<table>
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<tr>
<th>Development Status and Plans for Flight Readiness</th>
<th>Description</th>
<th>Date to be Completed</th>
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<tr>
<td>Component and/or breadboard validation in relevant environment</td>
<td>An engineering model ion thruster, functionally identical to the flight ion thruster, was tested for 8,000 hours at full power. The flight ion thruster, PPU, and DCIU have been protolight qualified.</td>
<td>Completed</td>
</tr>
<tr>
<td>System/subsystem model or prototype demonstration in a relevant environment (ground or space)</td>
<td>The flight ion thruster, PPU, DCIU, and Xenon feed system have been environmentally and functionally qualified to protolight levels prior to use on DSI. A long-duration test with flight hardware processing 125 lb/sec of Xenon and using the full throttle range of the system</td>
<td>Completed</td>
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<td>Dec. 2000</td>
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<tr>
<td>Actual system &quot;flight proven&quot; through test and demonstration (ground or space)</td>
<td>Complete mission profile as primary propulsion system for DSI</td>
<td>Dec. 2000</td>
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-23-
Technology database for PI missions - Advanced Micro Controller

New capabilities enable new opportunities
MIDEX/SMEX/Discovery/ESSP

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Description of Technology

The Advanced Microcontroller (AMC) is the world's smallest space-qualified self-contained computer system. It was designed for high-impact, cold-temperature applications on the Martian surface (30,000 G's, -120 deg C). The AMC has modest amounts of computing power (about the equivalent of an old "Apple II" computer), but achieves this in the size of a postage stamp (0.8" x 1.2"), the mass of a few potato chips (3 grams), and 1/20"-watt of electrical power. Unlike an "Apple II", the AMC packs an impressive built-in instrumentation capability: six serial communications ports, 32 digital discrete lines, an additional 32 analog input lines, and eight presentable analog outputs. The AMC runs off of its own internal clocks (either 10 MHz or 200 Hz for ultra-low-power) or an externally provided time reference. Perhaps one of the most intriguing features of the AMC is its reconfigurable programming. Unlike many other computers, the AMC can be reprogrammed up until final integration, under electrical control; no de-integration is required. This versatility can save many thousands of dollars in any application. The AMC can also "save" data to its non-volatile memory, giving the AMC enough "smarts" to finish a task when interrupted by power removal, which is expected to occur at several points during the Deep Space 1 mission.

Applicability

Potential to support numerous applications where modest amounts of processing are required in dimensionally-constrained and/or remote locations for a minimal size, weight, and power consumption. Such applications include motor controllers, cryocooler refrigerator controllers, distributed health and status monitoring systems, configuration management processors, safety interlock protocol management, security systems, miniature weapons computers, space probe central control processor, and jet engine control. Will be useful in large satellites and high-performance systems as well, since these systems also have needs for lower tier processing, which can be offloaded to one or more AMC units. Beneficial to Deep Space Missions

Extremely high function-to-power, measured not just in the raw processor performance but in the degree of functionality accomplished. A single AMC can monitor and control a large variety of signals in low-level instrumentation. Multiple units can be employed with less size, weight, and power penalty than a single copy of any other system in its class. It can operate with extreme cold, radiation, and shock, and new versions can be quickly developed with much higher radiation tolerance.

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<td>System prototype demonstration in a space environment</td>
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<tr>
<td>Actual system completed and &quot;flight qualified&quot; through test and demonstration (ground or space)</td>
</tr>
<tr>
<td>Actual system &quot;flight proven&quot; through successful mission operations</td>
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</tbody>
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Advanced Micro Controller
# NMP Technology Covers Wide Spectrum of Opportunities

<table>
<thead>
<tr>
<th>Cross-Enterprise Technology Program Thrust Areas</th>
<th>Current NMP Validation Contributions (DS1,2 &amp; EO1,2)</th>
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- **Vibrant Validation Flight Schedule**

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- **Continuous Improvement to Meet Changing Enterprises Needs**
  - Flight Validation Technology Inventory
  - Process Improvements
  - Smaller & More Frequent Flights