
- $17.65 billion in FY14 for NASA, only slightly below what President’s Request. The FY13 budget was about $16.9B, so FY14 is a real improvement.
  - includes funding for the agency's major space and science initiatives, including a crewed mission to Mars by the 2030s and full support for JWST.
  - This back-off from automatic sequestration spending cuts is important as NASA must budget for the long term and needs consistent funding sources.

- The spending bill would give NASA:
  - $3.1 billion for manned missions, including $1.2 billion for the Orion multi-purpose crew vehicle that will eventually carry astronauts to Mars and $1.9 billion for the Space Launch System that will rocket.
  - $696 million for commercial space activities, mainly to further development of private spacecraft to carry astronauts to the International Space Station.
  - $5.2 billion for science missions, including $80 million for a mission to explore Europa, one of Jupiter's moons.
  - STMD (Technology) gets $576M...FY13 was $614M, and about $626M was expected for FY14, so adjustments are needed. Major hit to Center Innovation Fund. STMD is the primary source for technology funding.
• Starting Point - State of Art (SOA)
  End Point - Capability Performance Goal
  Time Frame - 20 Years
• Capabilities Driven approach
  • Capability Need Driven - Includes ONLY the Technology That Aligns with a NASA Mission Class and Design Reference Mission (DRM)
• Content - Expanded & Updated
  • Includes Information Technology, Radiation, Space Weather, Avionics, and Orbital Debris
  • Uses New Science Decadal Surveys and Design Reference Mission Plans for Human Missions
  • Uses Standardized Definitions, Acronyms, Symbols, Format, and Graphic Styles
• Type of R&D Included
  • Applied Research and Development (Basic Research now deleted – addressed elsewhere)
  • Push Technology and Pull Technology
  • Removes Technology That is now Developed or Has No Need
• 2014 Technology Roadmaps will define WHAT could be done to address DRM technology needs. This will form the basis for the next Strategic Technology Investment Plan
• NASA Internal effort – contractor input not sought at this time.
• Public Release – December 2014 planned
TA ROADMAP SCOPE TO BE EXPANDED

Technology Roadmap Update

Will Consider:
- Updates in Science Decadal Surveys
- Human Exploration Capability Work
- Advancements In Technology

Will Include:
- State-of-Art
- Technology Challenges
- Capability Needs
- Performance Goals

Expanded Scope
- Aeronautics Technology
- Information Technology
- Radiation
- Space Weather
- Avionics
- Orbital Debris

Strategic Technology Investment Plan Update

Will Consider:
- New Priorities
- Current Investments
- Unmet Needs
- Partnerships & More
Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
ADDITIONAL GUIDELINES

• HEOMD (Operations) and SMD (Science) will provide Design Reference Missions (DRM) – prime mission set and likely mission set for the 2020’s - for the 10-20 year time frame

• DRMs to be top level. Will help guide identification of needed future technologies.

• Review by NRC not currently planned, but their comments from first Roadmaps will be considered.

• Significant Center-level involvement is included

• Roadmaps to address all NASA Mission Directorates
### NASA Space Technology Roadmap (STR); the 15 Technology Areas (TAs) identified by OCT

<table>
<thead>
<tr>
<th>TA01</th>
<th>TA02</th>
<th>TA03</th>
<th>TA04</th>
<th>TA05</th>
<th>TA06</th>
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<tr>
<td><img src="image1.png" alt="Launch Propulsion Systems" /></td>
<td><img src="image2.png" alt="In-Space Propulsion Technologies" /></td>
<td><img src="image3.png" alt="Space Power &amp; Energy Storage" /></td>
<td><img src="image4.png" alt="Robotics, Tele-Robotics &amp; Autonomous Systems" /></td>
<td><img src="image5.png" alt="Communication &amp; Navigation" /></td>
<td><img src="image6.png" alt="Human Health, Life Support &amp; Habitation Systems" /></td>
<td><img src="image7.png" alt="Human Exploration Destination Systems" /></td>
<td><img src="image8.png" alt="Science Instruments, Observatories &amp; Sensor Systems" /></td>
<td><img src="image9.png" alt="Entry, Descent &amp; Landing Systems" /></td>
<td><img src="image10.png" alt="Nanotechnology" /></td>
<td><img src="image11.png" alt="Modeling, Simulation, Information Technology &amp; Processing" /></td>
<td><img src="image12.png" alt="Materials, Structures, Mechanical Systems &amp; Manufacturing" /></td>
<td><img src="image13.png" alt="Ground &amp; Launch Systems Processing" /></td>
<td><img src="image14.png" alt="Thermal Management Systems" /></td>
<td><img src="image15.png" alt="Aeronautics (NEW)" /></td>
</tr>
</tbody>
</table>

**Note:** These TAs now being commonly used for categorizing STP elements
Space Technology Roadmap Technical Areas + Additional Areas

- **TA01** - Launch Propulsion Systems
- **TA02** - In-Space Propulsion Technologies
- **TA03** - Space Power & Energy Storage
- **TA04** - Robotics, Tele-Robotics & Autonomous Systems
- **TA05** - Communication & Navigation
- **TA06** - Human Health, Life Support & Habitation Systems
- **TA07** - Human Exploration Destination Systems
- **TA08** - Science Instruments, Observatories & Sensor Systems
- **TA09** - Entry, Descent & Landing Systems
- **TA10** - Nanotechnology
- **TA11** - Modeling, Simulation, Information Technology & Processing
- **TA12** - Materials, Structures, Mechanical Systems & Manufacturing
- **TA13** - Ground & Launch Systems Processing
- **TA14** - Thermal Management Systems
- **TA15** - Aeronautics

Additional Crosscutting document
- Crosswalks – e.g., All Technical Areas that include Information Technology (IT), Radiation, Avionics, etc.
- Dependencies

- Space Weather Tech
- Information Technology Section Expanded
- Include NITRD and more
- Orbital Debris TA5, TA7, TA10
**2014 Roadmap Team**

* Theodore Swanson (GSFC), Chair

Walt Bruce (LaRC)

Craig Dinsmore (JSC)

* Chris Kostyk (DFRC)

Mark Lysek (JPL)

* Brian Motil (GRC)

* Steve Rickman (JSC-NESC)

Ryan Stephan (LaRC)
The NRC’s 2012 Report on NASA’s Roadmaps


DISCLAIMER: The following slides are taken from the NRC briefing to NASA; they should not be interpreted as the Agency’s position, priorities or plans.
**Thermal Protection Systems:** Develop a range of rigid ablative and inflatable/flexible/deployable thermal protection systems (TPS) for both human and robotic advanced high-velocity return missions, either novel or reconstituted legacy systems.

**Zero Boil-Off Storage:** Accelerate research on advanced active and passive systems to approach near-zero boil-off in long-term cryogenic storage.

Radiators: Develop improved space radiators with reduced mass.

**Multifunctional Materials:** Develop high-temperature multifunctional materials that combine structural strength, good insulating ability, and possibly other functions.

**Verification and Validation:** Develop, verify, validate, and quantify uncertainty analysis requirements for new or improved comprehensive computer codes for thermal analysis.

**Repair Capability:** Develop in-space thermal protection system repair capability.

**Thermal Sensors:** Enhance thermal sensor systems and measurement technologies.
NRC 2012 Observations on NASA’s Original Technology Roadmaps

Basically the NRC report is a strong endorsement of NASA’s need to emphasize technology development

- “Success in executing future NASA space missions will depend on advanced technology developments that should already be underway”
- “NASA’s technology base is largely depleted”
- “Currently available technology is insufficient to accomplish many intended space missions in Earth orbit and to the Moon, Mars, and beyond”
- “Future U.S. leadership in space requires a foundation of sustained technology advances”
- “Technologies prioritized in this study represent a foundation upon which to build the strategic goals outlined in the 2011 NASA Strategic Plan”
NRC Key Findings

• “NASA does not and cannot set its own strategic direction. A national consensus is required
• There is no national consensus at this time
• The administration should lead in developing a consensus, working with Congress, and holding technical consultations with potential international partners
• President Obama’s proposal that an asteroid be the next destination for human spaceflight has not won broad support within or outside NASA, undermining the ability to establish a strategic direction.
• There is a mismatch between the programs Congress and the White House have directed NASA to pursue and the resources provided to accomplish them”.
Goddard's NASA Mission

- **Science, Exploration, and the Technology to support these Missions**
  - Goddard Space Flight Center (GSFC) and the Jet Propulsion Lab are the prime science satellite development centers for the agency, both Earth Science and Space Science
  - Technology funding gradually returning

- **Goddard Core Focus Areas**
  - Cradle to Grave Effort on Science Satellite Projects
  - Earth and Space Science Missions
  - JWST is fully funded and top priority
  - Weather satellites for NOAA
  - Space Communication and Navigation

- **Thermal Control applies to all areas!**
NASA GSFC Recent Launches

- **LRO** 6/09
- **SDO** 2/10
- **NPP** 9/11
- **LDCM/OLI/TIRS** 2/13
- **MAVEN** 11/13

- **MLAS** 7/09
- **GOES 15** 3/10
- **MSL/SAM** 11/11
- **NEXT GEN TDRS** 1/13 and 1/14
- **LADEE** 9/13

Ames S/C with GSFC assist
NASA GSFC Future Missions

- GPM
- JWST
- NextGen TDRS
- Nicer
- LCRD – hosted payload
- ICESAT-II
- OSIRIS-REX
- GOES-R
- ISS/RRM
- JPSS
- MMS
- DSCOVR

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Current Missions at Goddard

- Missions recently launched;
  - TDRS Next Generation Comsat, launched 1/13 and 1/14
  - LDCM – Landsat Data Continuity Mission, launched 2/13
  - LADEE – In lunar orbit, launched 9/13 from WFF, Ames mission with GSFC assist, GSFC Laser-com Demo
  - Mars Atmosphere and Volatile EvolutioN (MAVEN) to orbit Mars, launched 11/13
  - Robotic Refueling Mission (RRM) on ISS – demonstrate robotic servicing
Missions in Work:

- **MMS** – 4 satellites - Explore Earth’s Magnetic Field, launch in 2014
- **ICESat-II (2015)** – Uses lasers to measure polar ice sheet thickness (or lack there-of)
- **DSCOVR** – Triana missions revived, launch in 2014, funded by NOAA/AF
- **TDRS** – additional S/C in Integration and Test
- **LCRD** – Laser Communication Relay Demo – to be flown on Loral/Comsat, launch in 2016
- **OSIRIS-REX** – Asteroid sample return, OVIRS instrument at GSFC, launch in 2016
- **Orbital Antares ISS** commercial servicing from Wallops, launch in 2013
Missions in Work:

- **GOES-R** - next generation of Geosynchronous weather satellites, launch in 2015
- **JPSS** – Joint Polar Satellite System – NPP follow-on Weather Satellite
- **Global Precipitation Mission (GPM)** to provide data for Weather forecasting, launch 2/27/14
- **JWST** – Large Telescope Mission scheduled for launch in 2018
  Very challenging thermally, testing underway, going well.
- **NICER** – ISS X-ray Science Mission
Thermal Challenges within Current Missions
GOES-R Spacecraft

- S/C Design at Lockheed/Martin in Newtown, PA, I & T in Denver.
- Newtown plant closing in 2015, moving to Denver, loss of expertise
GOES-R GLM Loop Heat Pipe Flight

Issues being worked regarding software control of LHP’s
GOES-R ABI Instrument

Working Issues with inadequate sub-cooling and gravity induced flow.
ICESAT-2/ATLAS Instrument Loop Heat Pipe Cooling
Redundant lasers are cooled via a single Laser Thermal Control System (LTCS) consisting of a constant conductance heat pipe (CCHP), a loop heat pipe (LHP), and a radiator.
Heat pipe and LHP both operating in reflux

Additional Control heater power needed in 1-G
Global Precipitation Mission – Open Architecture complicates Thermal Design
GPM at launch site in Japan
Laser Comm Relay Demo (LCRD)

- Flying as Hosted Mission on LORAL comsat (first for NASA)
- Demonstrates Laser Communication Technology as possible precursor to next TDRS or planetary missions
- Partnership with MIT/Lincoln Labs
Detector temp below 105 K, optics below 160 C, relies on 2 stage radiator (passive) and heat straps. “Orbits” asteroid, relies on transient behavior to meet requirements.
OSIRIS-Rex begins observations in terminator orbit at 1 km altitude, returning to +X sun point upon completion of observation.
### Launch to ISS

**NICER Transport & Installation on ISS**

---

**SpaceX launch option:**

**Falcon 9 rocket and Dragon vehicle**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Location</th>
<th>Orientation</th>
<th>Heater Power Allocation</th>
<th>Duration</th>
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<td>Dragon Trunk</td>
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<td>?</td>
<td>8-10 min</td>
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<td>Orbit, Proximity Ops, Grapple &amp; Berthing</td>
<td>Dragon Trunk</td>
<td>any</td>
<td>80 - 100 W</td>
<td>days</td>
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<tr>
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<td>any</td>
<td>0 W</td>
<td>&lt; 6 hrs</td>
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<tr>
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<td>EOTP</td>
<td>any</td>
<td>204 - 302 W</td>
<td>hrs to weeks</td>
</tr>
<tr>
<td>Transfer to ELC</td>
<td>DEXTRE</td>
<td>any</td>
<td>0 W</td>
<td>&lt; 6 hrs</td>
</tr>
<tr>
<td>ELC...</td>
<td>ELC</td>
<td>lots</td>
<td></td>
<td>&gt; 2 yrs</td>
</tr>
</tbody>
</table>
**Mechanical**

Avionics Electronics Deck
- Al 6061-T6
- 6 Ti flexure to IOB baseplate (G = 0.01 W/°C each)
- PCM panels sandwiched between boxes and deck using NuSil

Instrument Electronics Deck
- Al 6061-T6
- 4 Ti flexure to IOB baseplate (G = 0.01 W/°C each)
- PCM panel attached to deck underside using NuSil

Radiator
- Al6061-T6, 2mm thick
- Bolted and NuSil bonded to top of MEB, GCE, & MPU
- Bolted to Elex Decks

**Thermal**

MEB  
GCE  
DPU  
MEB  
GCE  
DPU
Orbital Minotaur V LADEE Launch Thermal Analysis at WFF

- New area for GSFC Thermal Branch
- Included ground processing through launch
- Work done by Kan Yang with support from David Steinfeld
LADEE Launch could be seen over East coast
Wallop only has experience with Minotaur I:
Uses “Banana Bag” for control
• Mitigates solar load on solid motors
• A/C air controls environment inside
• Removed at launch
• $200k per use

LADEE launched aboard the maiden flight of the Minotaur V Launch Vehicle
• Wallops had no experience cooling Peacekeeper (PK) Solid Motors
• Orbital had no previously-developed scheme to cool PK Motors outside of air-conditioned gantry
  • No Banana Bag for PK motors (too heavy, bulky, does not fit in Gantry)
  • Orbital was not under contract to develop thermal control methods for Wallops ground ops
Suite of Ground Ops Analysis Cases

Transport of the Spacecraft and launch vehicle (LV) to the processing facility

Testing/Integration of the LV and Spacecraft in the launch processing facility

Transport of integrated LV components to gantry / Gantry stacking operations

Gantry Environmental Sources and Heat Flows

- Radiation to Cold Sky
- Convective Heating (or cooling) from Ambient Air
- Environmental Radiative Heating: Solar Flux, Earth IR, Ground Reflection
- Conduction from Launch Mount
- Convection with HVAC-controlled fairing air
- Conduction Through Motor Casing to Propellant
- Convection to Interstage and Fairing Internal Air; Radiation between Internal Surfaces
- HVAC Unit
- Launch Mount
- Fairing Purge Air
- Radiative heating (or cooling) from fairing walls
Launch Profile Thermal Loads

Heating of LV external surface (Solar Flux, Albedo, Earth IR, Aeroheating)

Convection to stagnant air (diminishes with loss of atmospheric pressure)

Initial Stages: ignition to burnout
Emerging Thermal Control Technologies

- GSFC’s SBIR Thermal Subtopic was discontinued in 2012, but was re-instated in 2014. 21 proposals received in our thermal subtopic, Jentung Ku is the subtopic manager.

- NESC funding received for 3 Development Activities

- IRAD funding received for several activities
Phase 2 Underway
Title: Software for Automated Generation of Reduced Order Models for Spacecraft Thermal Control

Company Name: CFD Research Corporation

Proposal #: S3.02-9436   COTR: Jentung Ku

Technology Description and Objective:

- Further expansion of Model Order Reduction techniques developed in Phase I.
- Benefits in solution time are clearly demonstrated in Phase 1 (> 20x speedup).
- Limitations of time and temperature dependent terms necessitating more frequent generation of the projection matrix are clearly identified.
- Offeror proposes solutions to minimize the frequency of regeneration of the projection Matrix to maintain speed improvement for larger class of models.

Proposal Objectives:

- Develop the approach to handle a larger class of thermal models (e.g. temperature/time dependent conditions).
- Goal of Phase II is to identify and execute methods to minimize the frequency of needing to regenerate projection matrix.
- Teamed with C&R (primary thermal software vendor) to further embed technology in end user product.
- Application Programming Interface (API) deliverable allows technology to be used in other disciplines (CFD, Structures, Controls, etc.)

Attributes

- NASA Applications:
  - James Webb Space Telescope, Laser Interferometer Space Antenna

- Primary SMD Division or Category:
  - !!! ANY NASA MISSIONS REQUIRING THERMAL ANALYSIS !!!

- Deliverables:
  - Application Programming Interface (e.g. DLL)

- PI: Dr. Yi Wang

- Consultants/Subcontractors: Brent Cullimore (C&R Technologies)

(September 10, 2010)
Thermal Coatings Technology Development

• **Qualifications recently completed**
  – Z93C55 (Alion Science and Technology), white, ESD dissipative silicate for use at geosynchronous orbits
  – MLP300 (AZ Technology) and ESD dissipative hybrid primers for bonding silicates to non-metallic substrates (e.g. carbon composite, polyimide films)
  – MH55 ICP (Alion Science and Technology), black, ESD dissipative silicate
  – STAMET coating (Astral Technologies) for replacement of vapor deposited germanium on polyimide film (GBK - exterior layer of MLI) for high electrical conductivity – partially funded by NESC. *Note that STAMET coating has been approved for use on GSFC missions*, however there is potential susceptibility to AO in low Earth orbits.

• **Current Development Activities**
  – Low absorptance layered silicate coatings to reduce absorptance below 0.13 at thicknesses less than 5 mils
  – Boron Nitride Nano-Mesh and Nanotube (BNNM) pigmented coatings (AMSENG) – Phase II SBIR and pigment post processing work for improved spray application

Contact: Mark Hasegawa, GSFC Code 546, (301) 286-4519, mark.m.hasegawa@nasa.gov
Description and Objectives:
Demonstrate an Atomic Layer Deposition (ALD) manufacturing method for multilayered deposition of Ir and low-z material source for an x-ray optic using a novel reactor design. Create recipe for iron oxide ALD for carbon nanotube growth.

Key challenge(s)/Innovation:
Develop enabling thin-film technologies that facilitate the current state of the art in coatings systems primarily for multi-layered materials applications as well as two-dimensional epitaxial structured elements.

Approach:
Demonstrate the applicability of a custom built in-house ALD system to coat Ir and a low-z material on glass and silicon substrates with our collaborator at UMD.

Milestones and Schedule:
- Reactor Check-out (Jan 2014)
- Alumina film growth (Feb 2014)
- Ir/Low-z film growth on multiple surfaces (May)
- Full Characterization (End Summer 2014)

Application / Mission:
- X-Ray Optics
- Sensors
- Multifunctional/layered structures

Collaborators:
- Dr. Raymond Adomaitis (UMD), CODES: 670, 630, 570

Space Technology Roadmap Mapping:
- Primary Technical Area: TA10
- Secondary Technical Area: TA08
- Additional Technical Area(s): TA12, TA03, TA14, TA11
- Applicable Space Technology Grand Challenge: New Tools of Discovery

Technology Readiness Level:
- Starting TRL: 2
- Anticipated Ending TRL: 4
Atomic Layer Deposition (ALD) Advantageous Properties

Epitaxial Growth

Artificial trench filled with an ALD nanolaminate
Image courtesy of Aalto University (Fl)

Multilayer consisting of:
Al2O3 - 25 nm
TiN - 20 nm
Al2O3 - 25 nm
Dr. Fred Roozeboom, NXP Semiconductors Research and
Dr. Erwin Kessels, University of Technology, Eindhoven

Schematic of a 3D battery integrated in a Si substrate.
The cross-section shows the various functional layers in the battery stack as well as the candidate materials.

A Program is underway to facilitate automated model conversion from ESARAD to TSS and ESATAN to SINDA/FLUINT. A TSS to Thermal Desktop conversion routine already exists.

The ESARAD to TSS path is fairly complete, but the SINDA/FLUINT to ESATAN converter is still in work. A Conversion routine for Thermica is also in work.

The product is a Windows based Graphical User Interface that will import the model in one format (TSS, ESARAD, or SINDA FLUINT, ESATAN) and export it to another format.

Applies to NASA/ESA projects such as JWST, Solar Probe, MOMA

Work will be done by Hume Peabody and Kan Yang of GSFC

Work is funded by NESC Passive Thermal Discipline Team, under Steve Rickman
The Graphical User Interface (GUI) for the ESARAD/TSS Conversion Routine
Embedded Electrohydrodynamic (EHD) Based Thermal Control - Jeff Didion/PI

**EHD/Capillary Hybrid:**
- Less Mass/fewer components; lower thermal resistance
- High heat rejection temperature
- More Effective Radiator (see figure on right)
EHD Validation Efforts

Technology Validation Status

• EHD Single Phase Pumping (Board Level Packaging)
  – May 2012 Variable Gravity
  – June 2013 Sounding Rocket (Univ. Of Nebraska – RockSat-C @ WFF); included additive manufactured PEKK parts
• Thin Film Evaporation – Variable Gravity September 2013
• STP-H5 – 2014/2015 EHD Multifunctional Plate
• ISS Thin Film Evaporation Experiment: 2016/2017
• Heat is absorbed over a large area (detector array or cryo tank) and rejected into a small area (cryocooler).
• An external power is applied to the capillary pump to serve as the driving force for fluid circulation.
Cryogenic Loop Heat Pipe (CLHP) for Large Area Cooling (Propulsion Tanks)

- All SS construction.
- Capillary pump: 1/4”OD x 1”L; wick: 1.2μm x 45% porosity
- Reservoir: 1/4”OD x 2.5”L
- Transport line: 1/16”OD x 90”L
- Because of size constraints, loop was limited to 2 loop backs
- Loop successfully tested with neon and will be tested with helium.

- CLHP built via SBIR program by TTH/Thermacore.
- NESC providing funding for further testing (Dr. Jentung Ku and Frank Robinson)
Critical need for integrated electronic systems with onboard processing

Flow boiling in microchannel coolers:
- > 100W/cm² heat removal capacity
- Compact size, low mass, low power

Lack of understanding of flow boiling in microgravity limits implementation

**Hypothesis:** Shear + surface tension forces dominate annular flow in microchannels, resulting in g-insensitivity

What channel dimensions and flow parameters provide g-insensitive behavior? What role do fluid properties play?
Approach: For hydraulic diameters of 0.1-2mm, determine orientation effects in 1-g, then validate results in 0-g.

Similitude required among flow regime and heat transfer parameters (CHF, HTC, ΔP) at various orientations for g-insensitivity determination.

Applications: Amplifiers, multi-chip modules, laser diode arrays.

Collaborator: Professor Avram Bar-Cohen/UMD.
• New Technology program underway at NASA, although funding is limited
• NASA/GSFC’s primary mission of science satellite development is healthy and vibrant, although new missions are scarce – now have people on overhead working new missions and proposals
• Future mission applications promise to be thermally challenging
• Direct technology funding is still very restricted
  – Projects are the best source for direct application of technology
  – SBIR thermal subtopic resurrected in FY 14
  – Limited Technology development underway via IRAD, NESC, other sources
  – Administrator pushing to revive technology and educational programs at NASA – new HQ directorate established