Inserting New Technology Into Small Missions

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Inserting New Technology Into Small Missions
The Future May Not Be as Bright as Two Years Ago!

- The number of deep space missions is increasing as we embark on a new era of exploration
- New missions are “faster-better-cheaper” and cannot afford large individual investments in technology
- A new process is needed to allow these missions to take advantage of the technological breakthroughs that are critical to getting the cost down while increasing the science
- The key is multimission technology development
- NASA will make institutional investments in technology to benefit sets of missions
- Continuous investment will provide a series of revolutions in technology to address common challenges in mission design and execution

Actual Increases Slower Than Predicted
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What Happened?

- NASA experimented with "Faster-Better-Cheaper" (FBC)
- These missions were certainly cheaper and faster – but "better" seems to have been forgotten
- Results included higher risk and cost overruns
- Reaction to recent deep space mission failures has been a reduction in the number of missions and an increase in the cost of the remaining missions

Mars Climate Orbiter

Mars Polar Lander

Technology was not a factor in either mission failure

- Independent reports on these failures and FBC have all recommended increased emphasis on new technology for FBC missions
- NASA is still committed to FBC, but it needs to be better-defined
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Faster-Better-Cheaper

- Successful FBC requires that the latest breakthrough technology be used
  - Increase mission performance (better)
  - Reduce mission cost (cheaper)
- The key is quick, smooth infusion of new technology
  - Infusion must be quick to reduce the time it takes to design, assemble, test, and launch the mission
- Infusion times have been reduced at JPL, but they have a long way to go
  - It takes about three years to move a newly-proven technology into flight
  - This is not good enough to react quickly to changes in flight programs
- Technology must be infused from all sources – not just internally
  - Other US government agencies
  - Foreign space agencies (ITAR constraints!)
  - Universities
  - Industry
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The Technology Life Cycle: The Four Major Epochs

- This is my view – there are many millions of others

Far-Term Research
- New ideas
- Understand feasibility
- Understand applicability

Crazy ideas

Mid-Term Development
- Determine potential capabilities
- Develop user advocacy
- Basic infusion plan

Potential Capabilities

Near-Term Engineering
- Focus on particular users
- Focus on specific applications
- Reduce risk

Ready to Fly

Validation
- Reduce risk
- Impedance matching to users

Technology Products
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Far-Term Research

- Crazy ideas are not usually tied to specific missions
- Funding for far-term research tends to be institutional (not funded by individual flight projects)
- Since NASA is organized by "Enterprises" (e.g. Space Science, Earth Science, ...) far-term research programs fall into two categories
  - Enterprise programs (focused on the needs of a NASA Enterprise)
  - Cross-Enterprise Programs
- Both kinds of programs exist currently within NASA
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Far-Term Research: TMOD

- JPL’s Telecommunications and Mission Operations Directorate (TMOD) leads an Enterprise technology program in the area of communications and navigation.
- The TMOD program spans all epochs of technology development, including far-term research.
- Spanning epochs allows a smooth transition between epochs.
- However, TMOD must maintain a proper balance between epochs.
- TMOD has been very successful in infusing technology.
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Example: Error-correcting Codes

- Error-correcting codes have been used for many years in deep space
- TMOD's technology program has been responsible for many breakthroughs in coding theory and in implementation of coding systems

- TMOD develops the ground equipment and demonstrates the flight capability
- Operational flight systems are developed by flight projects
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Example: Compression 4 GLL

- Before the Galileo mission, deep space missions used mostly “lossless” compression
  - Low compression ratios - typically no better than 2:1
  - Well understood, deterministic errors, caused mainly by data overflow
- Galileo now uses the Integer Cosine Transform (ICT) algorithm - similar to JPEG industry standard for photographic images
- Compression algorithms were part of TMOD’s far-term research program for several years before the Galileo high-gain antenna failed to deploy
- Infusion was fueled by the need to recover a potential data loss of four orders of magnitude
- Infusion took only two years
- TMOD’s technology saved the Galileo mission

0.2 Bits/Pixel, RMSE ~ 20
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Far-Term Research – Cross Enterprise Program

- NASA’s Space Base Technology program (AKA 632, CETDP) develops technology of benefit to multiple NASA Enterprises
- SBT concentrates on far-term research
- Transition to subsequent epochs has had mixed success
- Some very big successes have come out of the SBT
- Traditionally, such programs have been assembled from tasks selected locally at NASA centers
- There is a recent trend toward selection by NASA Headquarters through open competition

It’s the American way
- This insures NASA gets the benefit of the best ideas from all (American) sources of technology
- This makes it difficult to run a cohesive program of related tasks
- This also makes it hard to provide funding stability for research groups at NASA centers
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Example: Space Optical Interferometry

- The SBT program developed the concept of a space optical interferometer
- Demonstrated concept on the ground using optical observatories and laboratories
- Transferred technology to mid-term development in the NASA Origins Program
  - Demonstrated feasibility in laboratory experiments

SBT technology will enable the TPF mission
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Example: Mars Technology Program

- Mars technologists work closely with Mars mission designers
- Technology requirements are gathered and honed
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Near-Term Engineering

- Typically funded by single flight projects programs, or consortia
- Retire most risk by addressing specific requirements of potential users
- May construct engineering models and prototypes
- The Mars Technology program is a good example of this
- X2000’s First Delivery Project as of two years ago was a good example
  - Recently, it was completely merged into Europa Orbiter project
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Example: Small Deep Space Transponder (SDST)

- The SDST technology was needed by many missions
- No single mission could afford to develop this epoch of technology
- A consortium was established with many missions contributing funding and oversight
- The SDST is now the standard deep space transponder and is used on all deep space missions

SDST Capabilities:
- Deep Space Network Compatible
- X-band Receiver, X-band and Ka-band Exciters
- 2.5 dB Noise Figure (Nominal @ 25 o C)
- -156 dBm Receiver Threshold
- Temperature Compensated Receiver VCO
- Low Exciter Spurious, Phase Noise and Allan Deviation
- Radio Science Mode (USO Input Available)
- 40 ns Maximum Ranging Delay Variation
- 3 ns Maximum Carrier Delay Variation
- Bus Interface - Mil-Std 1553/1773 Options
- External Power Converter Synchronization Capability
- Operates Under Launch Environments
- Radiation and SEU Resistant
- Internal Telemetry Modulation Encoder
- Internal Command Detector
- Mounting in Either of Two Axes
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Validation

- Validation of a new technology in a flight environment is often the most costly and time consuming epoch
  - There are not enough launch opportunities to test all new capabilities in space in a reasonable time
- However, nothing reduces the perceived risk to a project manager like validation!
- We must be careful to choose the right capabilities for validation
- We must strive to create more flight opportunities
- The New Millennium Program is NASA's premiere validation effort
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Example: Ka-Band Communications

- The Mars Observer spacecraft carried a Ka-band experiment
  - Although the mission failed, the experiment was successful
- Mars Global Surveyor also has a Ka-band experiment
- These were both flights of opportunity

Ka antenna mounted on front of HGA had the same beam width as the HGA at X-band
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Example: Ground System Validation Using DSS13

- TMOD uses a dedicated 34m R&D antenna at its Goldstone complex to demonstrate new ground system technology
- Deep Space Station 13 (DSS13) is designed to allow multiple simultaneous validations in a near-operational environment
- DSS13 can be wired to the rest of the Deep Space Network to do systems-level validation
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Example: LEO-T Infusion Through Industry

- LEO-T’s technology dates from JPL work performed in the 70’s with people who eventually formed SeaSpace
- SeaSpace, in the early 90’s, sold ground stations that could automatically acquire weather photos from satellites
- Through a JPL collaboration, SeaSpace was able to add the technology to communicate with NASA’s spacecraft in Earth orbit
- Now SeaSpace sells autonomous terminals to NASA (through GSFC)

SeaSpace 5m antenna in radome at JPL

Prototype receiver and support electronics
• Technology programs, like TMOD, that span all the epochs have the most success in these transitions
• TMOD’s use of a multimission engineering office also makes infusion smoother
• For other programs, these transitions are one of our major challenges
• Infusion plans should be developed early in the life cycle
  – Stay “plugged in” to the desires of future mission planners
  – Need to focus in on potential applications early
  – Need analysis of benefits, costs, and risks early
• Close coordination between programs in different epochs, and users, is critical
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A Model to Follow

- Technology development does not happen in a vacuum
- We can think of technology development (with its epochal life cycle) as a pipeline of continuous change
- There are similar pipelines for missions and for science programs
- These pipelines all interact and have influence on one another
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Conclusions

- NASA has not found the perfect solution to infusion technology into small missions
- NASA must continue to improve technology insertion in order to succeed at FBC
- NASA's experience with different types of technology programs has resulted in a wealth of knowledge about things that work, and things that do not work
- We have found certain things that greatly enhance the success of technology insertion into missions
  - Solid, stable investment for all technology development epochs
  - A strong mechanism to capture "crazy ideas" from all sources, without stifling NASA's internal creativity
  - Alignment with and advocacy from potential flight users
  - Early planning for transitions between epochs and for infusion