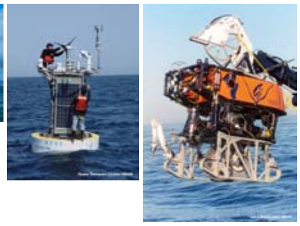
Platforms Engineering
Strategic Planning Update



M. Chaffey - A. Hamilton - K Headley
R McEwen - E Mellinger
T O'Reilly - Y Zhang

MBARI Offsite Meeting
March 21-23, 2005
Napa, CA

Presentation Overview

Research
- Planning Process
- Draft Plan
- Environmental Assessment
- Science Input

Analysis
- Core Competencies → Potential Directions
- Challenges → Meeting Challenges

Action

- Science Story

Strategic Planning

"Plans are worthless, planning is essential."
- Dwight D. Eisenhower

- Objectives for planning process
  - Define our mission and vision of the future
  - Establish common understanding of strategic issues through discussion
  - Define a common vocabulary
  - Create a plan for implementing our mission
  - Communicate this to group members and stakeholders

Strategy Stratagem

- Align with MBARI Strategic Plan
- Involve stakeholders (scientists, operations) early and often
- Follow existing practices for documenting our plan

Planning Activities

- Reading list
- SWOT analysis
- Scientist meetings
- Technology survey
- Discussions
- Draft plan

Strengths	**Opportunities**
Weaknesses	**Threats**

Presentation Overview

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- Core Competencies → Potential Directions
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Action

Science Story

Andy

Science Meetings

Held 3 meetings with MBARI Science Staff

<u>Topics:</u>

– Current research interests that would benefit from platform engineering development.

– Concerns related to engineering project selection and structuring at MBARI.

– Methods of improving interactions between the engineering and science divisions.

Research Topics

- Primary Ocean Productivity (K. Johnson)
  - Drifting Profilers (Chem. Sensors on ARGOS Floats)
  - Ocean wide Coverage
- Seafloor Mapping (D. Caress)
  - Multibeam, Sub-bottom, Side-scan
  - Institute Support Necessary
- Marine Geology (Charlie Paull)
  - Flux of Fluids and Gasses Through Seafloor
  - Transport of Sediment Across Seafloor
- 2nd Meeting: Scholin, Barry

Concerns

- Too many projects, lack of consistent focus.
- Projects take too long, need to find the balance between immediate results and generalized utility.
- Large, engineering driven projects are susceptible to a disconnect between engineering and science.
- Concern that rush to move on to new projects may leave potential of current projects unrealized.
- Concern that new engineering thrusts may neglect importance of ROV developments.

Improving Interactions

- Recognize range of projects that engineering participates in: Small science driven projects on one hand, major engineering initiatives on the other.
- Structure large projects with more incremental implementation steps. Don't start on these projects without refined science plans that include shorter duration accomplishments.
- Involve engineering staff in traditional science cruises.
- Improve relevance of new engineering driven proposals to current science interests.

Technological Limitations to Science

Energy constraint
- Mobile platforms (e.g., AUVs) can only carry limited payloads due to energy constraints
- Mobile platforms' operation endurance is limited by on-board energy

Lack of measurement techniques
- Measuring number of particles in water
- No measurement techniques between bulk properties and microscopic assay
- Difficult to observe and characterize thin layers (and other morphologies) of water (layers are easiest to find)
- Chemical sample processing time

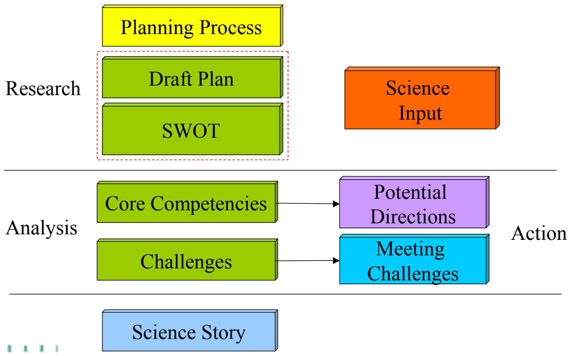
Lack of signal detection/classification techniques
- Robust event detection algorithms

Sensor accuracy
- Sensor drift

Reliability
- Endurance of platforms/cables/instruments
- Biofouling

Size and Scale of Ocean vs available observing technology

Presentation Overview



Draft Plan

- Mission Statement
  Inform and implement the development of platforms and related technologies at MBARI
- Charter
  - Support MBARI's institutional mission
  - Maintain a strategic plan for ocean observing platforms and technologies
  - Provide expertise and guidance in platforms and related technology
    - Science, Operators, Management, Community
    - MBARI Engineering
- Composition
  - Platforms Engineering representatives (5)
  - Research Engineering representatives (1)
  - Science representatives (?)

What is a platform?

A platform provides and manages shared resources to scientific instruments

- Multiple science users, shared resources
  - Energy
  - Physical space
  - Data storage and telemetry
  - Navigation, propulsion, location
  - Access to data
- Common interface standards
- Reconfigurable

Example Platforms

Platform — Not Platform

ROV
AUV
Moorings (MOOS)
Cabled Observatory (MARS)
Gliders

Benthic Rover
AUV Dock (not for science)

Biosa (may be either)
LOBO Moorings (like OASIS)
OASIS (became platform later)

CTD (access to the data, management)
ESP (being developed as instrument)
Raman Spectrometer
Benthic Respirometer

- Platform status implies responsibilities
  - Development path
  - Engineering methods, quality
  - Operation, Management
- It is important how management views projects

Draft Plan

- Metrics for success
  - Metrics for engineering success in MBARI strategic plan
  - Adoption of platforms technologies and standards by MBARI and community
  - Solicitation and external recognition of expertise in platforms

SWOT

Strengths	**Opportunities**
Weaknesses	**Threats**

SWOT Results

Strengths

- Skill sets and experience
- Deployment resources
- Relatively stable funding
- Access to scientists
- Latitude in setting direction

Opportunities

- Community initiatives
- New platform types
- Emerging technologies
- Collaborations
- Proposal process reform

SWOT Results

Weaknesses

- Understanding user needs/domains
- Diversity of stakeholder needs/agendas
- Resource issues
  - Fixed size and composition of core engineering (missing expertise)
  - Number of operational systems
  - Limited basic research capability
  - Technical support, lab space (excellent quality, need more)
- Nature of platforms
  - Technology push more than science pull
  - Long, expensive, high risk development cycles

Environmental Survey Results

Weaknesses

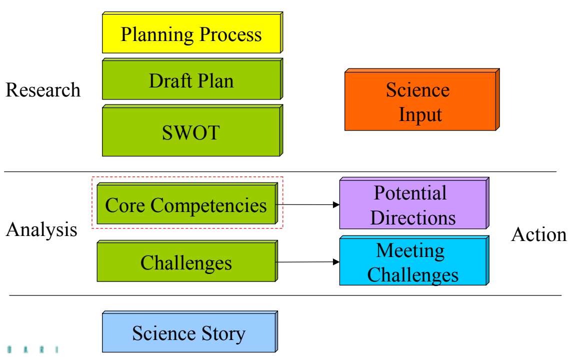
- Skills Related
  - Science literacy (hotly debated)
- Tracking tech/science trends
- Project Management
  - Quantitative comparison of platforms: economics, science value

Environmental Survey Results

Threats

Rapid changes in technology and science
Mis-alignment with Packard Foundation values
Wider restrictions within marine sanctuary
Competition
- Institutional
- Private sector

Presentation Overview



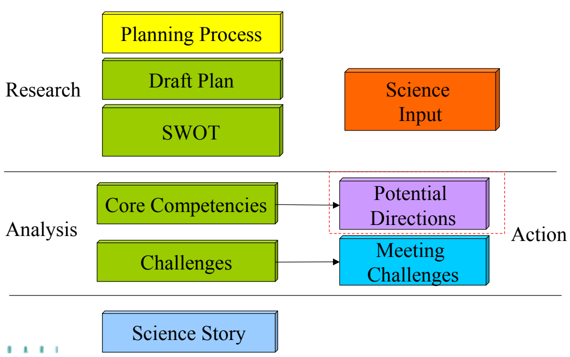
Core Competencies

- Systems architecture and integration
- Structural mechanical design
- Vehicles (operational systems)
- Power systems
- Application layer software
- Embedded software
- Control systems
- Hydrodynamics
- Vehicle dynamics
- Field experience in ocean engineering – designing things for the real world

Playing to Strengths

- High risk projects (difficult to get initial funding)
- Long cycle projects with intermediate science opportunities
- Design for technology transfer
  - –Lower barriers to adoption, operation, adaptation
  - –Requires investment in engineering, tooling, documentation
- Highly robust systems
  - –Grand Challenge: Long maintenance-free deployments
- Low-impact/green engineering
- Deep ocean systems
- Science literacy/specialization

Presentation Overview



Mark

Platforms Technical Directions

Major MBARI Platform Efforts

- AUV's
- ROV's
- Observatories
  - Cable-to-shore (high power!)
    - New experimental opportunities
  - Buoy based (low power)
    - Upper Water Column
    - Cable-to-the-seafloor

Minor Platform Initiatives

- Small vehicles (JETI-like)
- ???

The Opportunities in AUV’s

- The future of AUV's - Zhang, McEwen
- Sampling - Zhang

The future of ROV’s

- Big vehicles
  - Vehicle vs payload
  - Advanced control functions
    - Vision based mapping/mosaic building
    - Quantitative video
  - Vision systems and hyper-definition television

The future of HROV type vehicles

- Illustration of HROV?

Cable-to-shore Observatories

- Future of MARS?
  - MBARI contribution to operation
- Cables vs. Moorings (show graph)

The future of Buoys

- Traditional
- Event detection for other sampling methods
- Cable-to-the-Benthos
- Station keeping
- Low cost mooring arrays
- Cables vs. moorings

- Station keeping buoy

Technologies Relevant for Platforms

- Energy harvesting
  - Solar and Wave energy
- Acoustic communications
  - Energy cost per bit going down?
  - Data rates are now 10-40kB/sec. (Freitag et. Al.)
- Integrated sampling schemes (systems design?)
  - Moorings – Gliders - AUV's
- Satellite communications
  - Broadband..still showing promise.
- All enabled by increased electronic density/L power…..

Which Paths to Follow?

- Where can we have the most impact?
  - Given size of MBARI….
  - Our in-house science expertise…
  - Our unique facilities

Rob

The Future of Auvs

Outline

- Fundamental Auv Limitations
- Research Areas
  - General Near and Far Future
  - In Progress at Mbari
  - Example: Maximizing Range
    - Size Tradeoff
    - Efficiency and Energy
- Potential Mbari Auv R&D

Fundamental Auv Limitations

- Range & Energy
- Autonomy & Intelligence
- Speed of Response

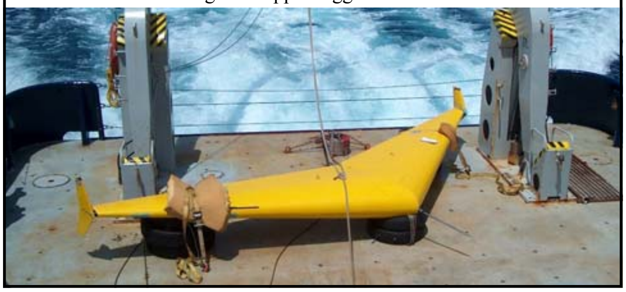
Auvs – Near (<5 Yrs.) Research Areas

- Increase Autonomy
  - Guidance (AI), obstacle avoidance, safemodes
- Acoustic Communications
- Adaptive Sampling
- Smaller Auvs (Remus, Ranger)
- Increase Auv Endurance and Range:
  - Hybrid Glider/Propeller
  - (Mbari: Reduce drag and hotel load)
  - Gliders

Auvs – Near (<5 Yrs.) Research Areas

- Increase Auv Endurance and Range
  - Increase Propulsion Efficiency: Gliders
  - Horton Wing at Scripps. Bigger & Faster

•Big v.s. Small



Auvs – Near (<5 Yrs.) Research Areas

- Energy Scavenging AUVs:
  - Solar
  - Thermal Glider

Auvs – Further Ahead (>5 Yrs)

- Improved synoptic (simultaneous) sampling with multiple AUVs. (AOSN)
- Increase Auv Endurance and Range
  - Higher energy density batteries or fuelcell
  - Increase propulsion efficiency (?) - Bio-memetic Propulsion (Flapping Fins, Robotuna)
- Autonomous Intervention. Auv Operates Like an Rov.
  - Hovering AUV with robotic arm (Stanford, Otter)
- Rapid Event Response
  - Network of AUVs triggered from docking stations (Larger?)
  - (Another way is a small Auv launched by small boat or aircraft)

Auvs – Ongoing R&D at Mbari

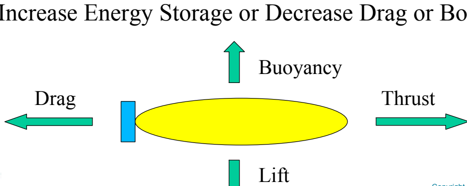
- Gulper. 12x1-liter sample and return with the AUV.
- Real-time assimilation of Auv data into ocean models for ocean prediction and adaptive sampling (AOSN)
- Obstacle Avoidance & Bottom Following
  - Unattended operations
- Prototype Dock and Vehicle
- Mapping Auv Development

Fundamental Auv Tradeoff: Large or Small?

- Large
  - More efficient: longer range and endurance
  - Deep-capable vehicles tend to be bigger
    - Heavier housings, denser foam (Remus vs. S[illegible]MS)
  - Larger and more varied payload capacity
  - Easier to maintain
- Small
  - Easily Launched; Facilitates Rapid Event Response
    - Small, fast and inexpensive boat
    - Ease of launch can avoid the necessity of a dock
    - Increased range with aircraft launch
  - Easy to transport and ship
  - Miniaturization (electronics, Mems) may greatly increase advantage in near future
  - Significantly Lower cost of support equipment (Ship, L&R)

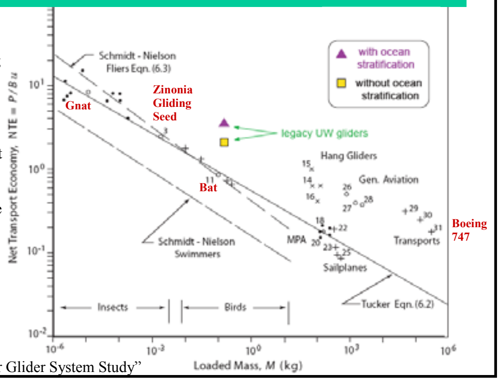
Maximizing Auv Range

- Gliders More Efficient But Slower
  - Seaglider: 6000km, 2.7 kWh, 0.25 m/s
  - Remus (propeller driven): 100km, 1kWh, 1.5 m/s
- Airplanes and Submarines Governed by the Same Equations for Mach < .3
- Increase Energy Storage or Decrease Drag or Both



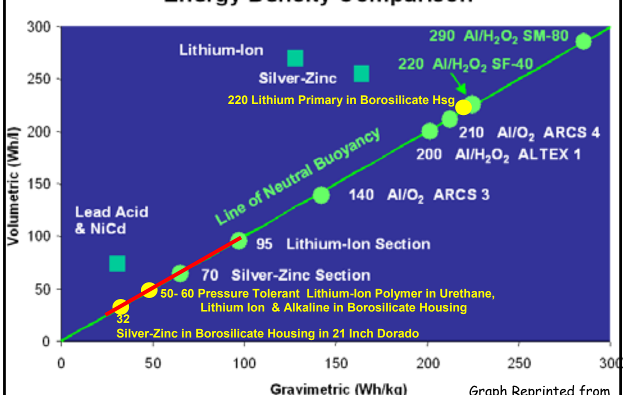
Net Transport Economy for Winged Flight

- Joules/Newton/m
- Includes Hotel
- 12 Orders of Mag
- More efficient means heavier
- Heavier vehicles go faster
- Nature is efficient
- BUT: Propeller driven Auvs don't require wings or lift
- Drag~r2, but Vol~r3



From "Underwater Glider System Study"

Energy Density Comparison

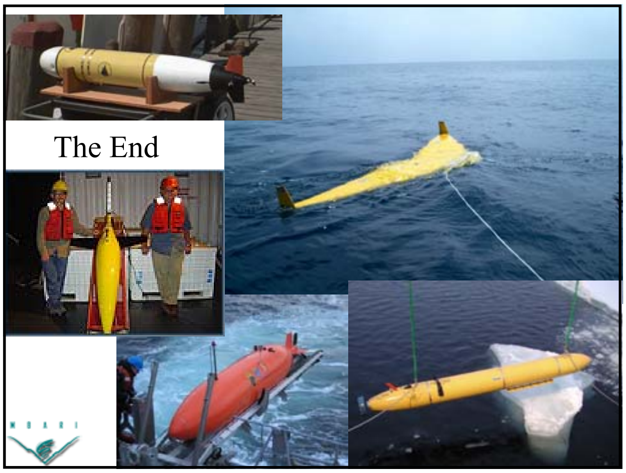


Graph Reprinted from Fuel Cell Technologies

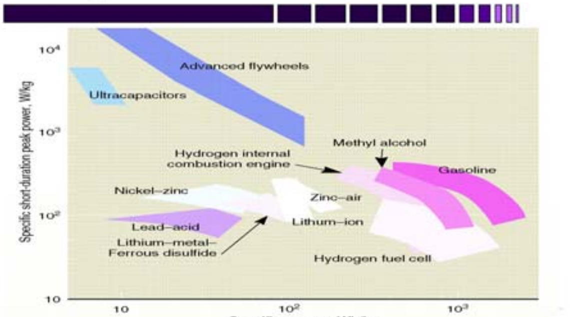
Mbari Auv Research Opportunities

- Increase Autonomy
  - Unattended Operations
- Decrease Event Response Time
  - Docking
- Multiple Auvs & Real-Time Ocean Model
- Increase Range
- Continue to Improve and Develop Mapping & Ctd Auvs based on Operational Performance
  - Incremental development is valid research

The End



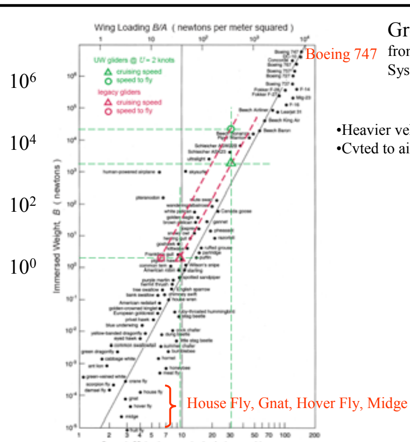
Comparison of Different Energy-Storage Technologies Regarding Peak Power and Specific Energy Characteristics



From http://www.eere.energy.gov/distributedpower/pdfs/review2q01pres/epripeacb_q2.pdf

Great Flight Diagram

from "Underwater Glider System Study"



- Heavier vehicles go faster
- Cvted to airspeed

$$U_A = \sqrt{\frac{\rho_W}{\rho_A}} U_W$$

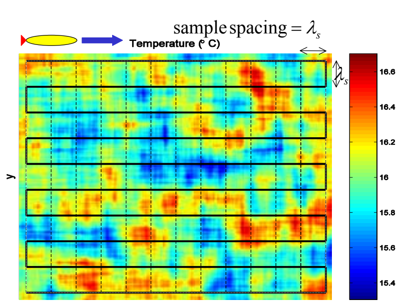
$$43 = \sqrt{\frac{1025}{1.25}} 1.5$$

Yanwu

Sampling the Ocean with Autonomous Underwater Vehicles

- An AUV survey design tool *.
- Ongoing work.

* J. G. Bellingham and J. S. Willcox, "Optimizing AUV Oceanographic Surveys", *Proc. IEEE Symposium on Autonomous Underwater Vehicle Technology*, Monterey, CA, pp. 391-398, June 1996.



$$\text{AUV traveled distance } L \approx \frac{\text{survey area } A}{\lambda_s}$$

$$\text{Survey duration } \tau = \frac{L}{V} = \frac{A}{\lambda_s V}$$

AUV Sampling Strategy Optimization

Objective:
Reconstruct a synoptic ocean field by non-synoptic AUV samples

↓

Energy consumption analysis | Reconstruction error analysis

↓

Survey parameters optimization

AUV Energy Consumption

$$E = (P_{propulsion} + P_{hotel})\tau$$

τ: survey duration

P_{hotel}: hotel power: control and sensors

$P_{propulsion}$: propulsion power = $\dfrac{\rho C_d S V^3}{2\eta}$

V: AUV speed

AUV Survey Error

Spatial aliasing (undersampling) error :

$$\varepsilon_\lambda = \frac{\text{spectral power over Nyquist wavenumber } k_{\text{Nyquist}}}{\text{total spectral power}}$$

where $k_{\text{Nyquist}} = \dfrac{1}{2} \cdot \dfrac{2\pi}{\lambda_s}$

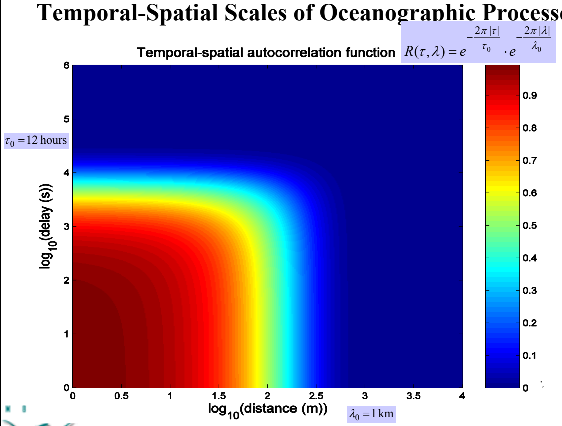
Temporal smearing (non - synoptic) error :

$$\varepsilon_\tau = 1 - \frac{1}{\tau}\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} R_t(q)\, dq$$

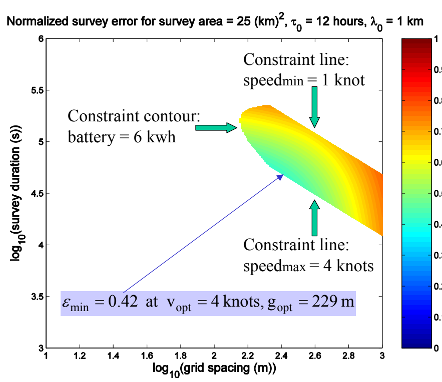
where $R_t(q) = E[X(t,r)\, X(t-q,r)]$

Total error $\varepsilon_{total} = 1 - (1-\varepsilon_\lambda)(1-\varepsilon_\tau)$

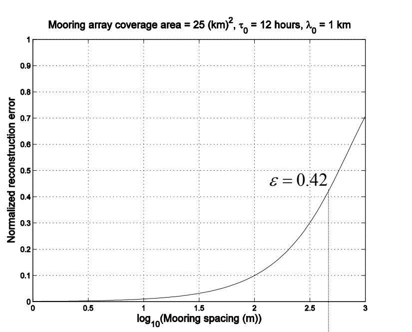
Temporal-Spatial Scales of Oceanographic Processes



AUV Survey Error Example



Reconstruction Error when Using an Array of Moorings

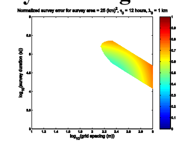


Mooring spacing = 500 m
Number of moorings = 100

Reducing Survey Error by Running Multiple AUVs

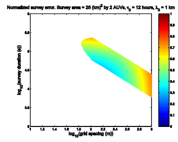
Running one AUV:

$\varepsilon_{\min} = 0.42$



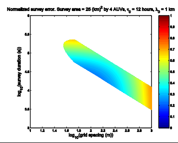
Running two AUVs:

$\varepsilon_{\min} = 0.32$



Running four AUVs:

$\varepsilon_{\min} = 0.24$



Ongoing Work

- Generalize the temporal-spatial survey error analysis by employing the Mingled Spectrum Principle*.
- Assimilate AUV data into an ocean model. Extend the AUV survey error analysis to ocean prediction error analysis.

* Y. Zhang, A. B. Baggeroer, and J. G. Bellingham, "Spectral-Feature Classification of Oceanographic Processes Using an Autonomous Underwater Vehicle", *IEEE Journal of Oceanic Engineering*, Vol. 26, No. 4, pp. 726-741, October 2001.

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Action

Science Story

Tom

Meeting the Challenges

- Institutional agreement on our mission
- Maintaining communication with science and operations
- Project selection
- Resource issues
- Building it
- Staying current on science and technology trends

Challenge: Setting Directions

- Need Platform assessment that's consistent with science and other engineering groups
  - Identify most promising Platform-related science and technical developments
  - Evaluate science impact, economics, social relevance, other criteria (quantitative where possible)
- Produce annual written platform implementation plan, with active science participation
  - External reviews?
- Distributed to institute
- Update as needed (every few years?)

Challenge: Project Proposal and Selection

- Platforms strategic council evaluates and ranks submitted proposals
- Communicate findings to management

Challenge: Resources

- Resource issues
  - Too many projects assignments per engineer results in greatly reduced efficiency
    - Recommend one major, one minor project per engineer
  - Must plan for and invest in community involvement: publication, collaboration, leadership, standards
  - Legacy system support – core engineering resources are needed by Support engineering
    - Provide management with best possible resource estimate for platforms

Challenge: Resources

- Form partnerships to complement expertise, ease resource pressures
  - Mission planning and scheduling: Ames, JPL
  - Autonomy: Stanford, Ames, JPL
  - Observatory infrastructure: SIO, Intel, Indiana University, LOOKING team
  - Mooring arrays

Challenge: Executing our projects

- Building it
  - –Platform schedule and design has major impact on many users and projects
  - –Intermediate science results are critical
  - –Design for technology transfer broadens community impact
    - Define project milestones
    - Users and developers agree upon how performance will be evaluated at milestones
    - Developers deliver capabilities according to milestones
    - Use appropriate design and implementation practices (e.g. Agile/XP software design)
    - Continuing developing of project management and systems engineering skills
  - –Accountability: need clear understanding of missed milestones
  - –Obtain adequate technical support

Staying current with science and technology trends

- Seminars (many free local opportunities)
- Conference attendance (science and engineering) – whether author or not
- Technical society memberships, participation
- Technical courses
- Contingency time for research

- Must be commitment by engineers and management to make the necessary investment

Ed

Platforms Engineering: *Building the Science Connection*

- This section is about *process* (how we connect with ocean science)… not about *content* (what we build for ocean science).
- Review: Goals of Re-Org
- Role of Platforms Strategic Council
- Interaction strategies
  - Incremental Development
  - Technology Briefings
  - Lab Leads
  - Informal Interactions

Mission of MBARI: *Make the Connection*

- "… to achieve a position as a world center for advanced research… and to do so through better instruments, systems, and methods…" (David Packard, 1995)
- The key to MBARI's success is the nucleation of good technology that enables leading-edge science. Neither alone will do.
- This implies a close working relationship between science and engineering… NOT an arms-length contract-house ("just give me the specs") relationship.

Why Re-Organize?

- Before Re-Org:
  - EE/ME/SE organization, project teams; difficult to maintain focus on a science field other than on an ad-hoc basis.
  - Science world-view (experiment -> measurements -> instruments -> systems) did not map onto Engineering organization; no designated points-of-contact other than ad-hoc basis.
- After Re-Org:
  - Engineers in "product line" teams; encouraged to focus on specific science field
  - **Strategic Council** provides formal focus and point-of-contact for Science/Engineering interaction

How Platforms Will Build the Science Connection

- Strategic Council
- Proposal Process
- Incremental Development
- Technology Briefings
- Informal Interactions

Role of the Platforms Strategic Council

- Provide a designated forum to which both Science and Engineering can bring platform-related *issues*
- Composed of 3-5 staff from each department.
- Example *issues* could include:
  - Future science directions – needs – emphases
  - Emerging technologies and trends
  - Evaluation, comment, prioritization of platform-related proposals
  - Monitoring progress, mid-course corrections for ongoing projects

Role in the Proposal Process

- Platforms Strategic Plan should be developed and/or endorsed by the Platforms Strategic Council
- Strategic Plan should identify science areas of emphasis and technology focus… near-term and long-term views.
- Strategic Plan should form backbone of the proposal evaluation process (like a town's General Plan)… help reject outlier proposals and keep limited resources focused.
- Strategic Council should have role in commenting on platform-related propsals (input to Management)

Other Interaction Strategies

- Incremental Development
  - *Require* all projects to deliver yearly (or more often) testable technology demonstrators. Keeps builders and customers focused; enables mid-course corrections; avoids “Five-Year Syndrome”
- *?*

Informal Interactions

- Technology Briefings
  - Designated engineers present latest tech in key areas (nav, batteries, AUVs, etc) to Strategic Council. Occasional basis, or after conferences (Oceans, etc)
- Science Briefings
  - Designated scientists summarize latest research thinking and directions to Strategic Council. Occasional basis (as above)

Informal Interactions (cont’d)

- Friday afternoon 4 PM “round table talks” – “teach-ins” and chance for free-ranging discussion & gossip
- Oceanography 101

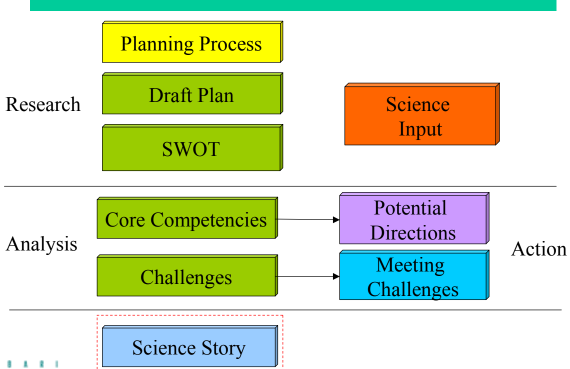
Tag Teams

- Platforms Engineering members assigned to follow activities (experiments, equipment development, cruises, papers, results) of specific scientists… report to whole Platforms Group.

Cruise Participation

- Can be a valuable opportunity for in-the-trenches view of research.
- Depends on first establishing good rapport with a lab or investigator.
- Role on cruise must be chosen carefully: must have a job, job should be non-menial.
- Example roles would be to field test a new off-the-shelf gadget, or to design and test a simple upgrade to some existing equipment.

Presentation Overview



John Ryan

Autonomous Event Response: Harmful Algal Blooms

Discussion

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