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Abstract

Far-term, impossible space missions can be directly relevant to today's R&D decisions relating to future space capabilities. That is the surprising premise of the Horizon Mission Methodology (HMM). Progenitors of revolutionary space capabilities of the future exist today as highly innovative or breakthrough space technology concepts or perspectives or not yet space-oriented new technology frontiers, collectively called breakthrough technology options (BTOs). The HMM was developed initially as a method of systematic analysis and evaluation of space-related BTOs. However, enthusiastic response from early users of the HMM has indicated much broader applicability - to technology innovation and R&D decision-making for space, aeronautics or indeed any field in which technology innovation is crucial. The HMM forces users into a shift of viewpoint - a change of paradigm; it forces them to stand in a different place conceptually to think about and evaluate choices for the future. Currently, the HMM is being applied to several different mission/technology areas. The HMM is described in this paper as are the objectives, scope, Horizon Missions and status of five study/workshops.

Introduction

"Breakthrough" technologies can provide revolutionary new space capabilities in the 21st century. Progenitors of those "breakthrough" technologies exist today as specific highly innovative space technology concepts or perspectives, fundamental space technology advances, or not yet space-oriented new technology frontiers. The collective term Breakthrough Technology Options (BTOs) is used in this paper to represent all of them. BTOs face a number of obstacles to their support or even consideration: novelty and hence unfamiliarity; a pragmatic uncertainty as to whether a BTO will really work; unpredictable validation dates; no stated requirements for them; and of course tight budgets, which tend to eliminate high-risk options. Because of these obstacles, no pathway exists for analyzing, evaluating and planning of space BTOs comparable to conventional technology advances. Therefore, the technology options and enabled missions that could provide the greatest benefits face the greatest hazards to their support.

The Horizon Mission Methodology (Refs. 1-6) was developed initially for the analysis of breakthrough-type space technologies and their enabled revolutionary space capabilities. However, response from early users of the HMM has reinforced and accelerated its development for a far broader applicability - for the analysis, planning and program management of breakthrough-concept, conventional and disciplinary technology research for space, aeronautics or indeed any field in which technology innovation is crucial.

Paradoxically, while Horizon Missions (HMs) are comprised of extreme technological capabilities chosen to be impossible, through the HMM they offer surprisingly relevance to current, perennial R&D questions. Which innovative technologies should be pursued, which dropped? What is the comparative value of fundamental technology research in different disciplines? What would be the impact of embryonic new technologies in a future system? What new capabilities may result from combining technology frontiers? If used to support conventional R&D planning and analysis, strategically-relevant HMs can provide stability to compensate for a rapidly changing program environment, direction in the absence of strong, clear goals, reference capabilities for advanced design and analysis, and an integrating mechanism for diverse technology interests.

The HM Methodology is a new conceptual territory of how to think about the technological future. It forces users into another paradigm through a procedure that guides thinking to be "non-linear" rather than remaining trapped in a narrow tunnel of linear projections of what seems possible.

Horizon Mission Methodology

Horizon Missions are defined to be hypothetical space missions having performance requirements that cannot be met, even by extrapolating known space technologies. The extreme performance requirements block the normal tendency to simply extrapolate known technologies. Horizon Missions therefore serve as an artifice to force conceptual

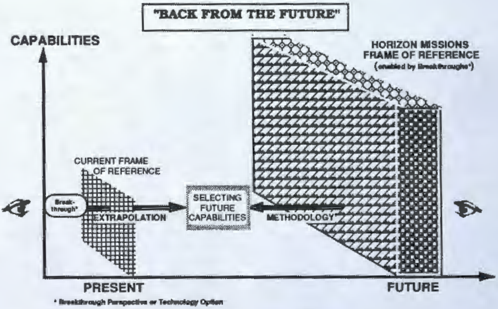

Figure 1. Horizon Mission Methodology

thinking toward innovative new functions and capabilities and away from simple projections and variations of existing functions and capabilities.

The Horizon Mission Methodology has been developed to provide a systematic, analytical approach for evaluating and identifying technological requirements for BTOs and for assessing their potential to provide revolutionary capabilities for advanced space missions. A graphic depiction of the Horizon Mission Methodology (Fig.1) helps to contrast the difference between the perspective it offers and conventional approaches for the study of BTOs. The primary decision faced by both mission and technology organizations is the Selection of Future Capabilities. When this selection decision is approached from the present, it is reached by extrapolating from the state-of-the-art, the traditional method of assessing BTOs. But this extrapolation is always filtered through the current frame of reference (or paradigm) of the technical organization. A paradigm has been defined as a set of rules and regulations (largely implicit) that establish boundaries on how we think and act and provides instructions for and measures of success within those boundaries. In more colloquial terms, it is "the way we've always done things", where the managers' or experts' judgments are based on old technical experience and on the framework of thinking that brought them their current success. Current paradigms thus either filter out or block from view many future manifestations of a BTO.

The HM Methodology instead goes into the future and defines a Horizon Mission (HM) as a new frame of reference. The HM must be beyond extrapolation and must be enabled only by BTOs. Given a relevant HM(s), we can then look "back from the future" to the pivotal decision - Selecting Future Capabilities. But now we approach it from the future - from a much broadened perspective on what could be possible.

Hypothetical, currently impossible HMs can be relevant to near-term technology and mission decisions for several reasons. The HMs can be selected to be relevant extensions of strategic goals; they can consist of functions that are analogous to those of near-term missions; and the Methodology provides a way back from the (future) HM technology requirements to near-term technology requirements.

The HMM has three stages, each involving two steps. For the ongoing space and aeronautics technology studies, several techniques have been devised for implementing each of the 6 steps. Different study purposes will require different strategies for implementing the steps.

The first stage of the Methodology is to go into the future to "Create a New Frame of Reference". In Step 1, one or more HMs are selected that encompass the scope of responsibilities of those using the Methodology. The HM can be adapted from existing mission concepts or custom-built for the study intent. This is an exciting and critical part of the Methodology. The HMs act as idealized, future products, capabilities or missions representing either exploratory or committed strategic directions of the organization.

In Step 2, the functional requirements of the mission are determined. These may be characterized by required capabilities and operations with appropriate performance levels identified. Insofar as possible, the requirements of the HMs should be taken directly from the literature to reflect the normal extrapolative technology thinking associated with advanced mission planning.

The second stage is to "Develop Alternative Technical Approaches" while in the new frame of reference. At this next step the HMM starts to diverge from traditional advanced concept studies and technology requirements definition. Initially in developing the HM Methodology, BTO technology requirements were to be derived from performance gaps of the HMs. These gaps were to be the difference between the required (but unobtainable) performance of the HM as found in the literature and the feasible performance of extrapolated current technology. However, the HM performance requirements described in the literature were found to be based on, and thus already carried with them, implicit assumptions about the technologies expected to be available. These implicit assumptions thus limited the mission concept, scenario and operations because they imposed current perceptions of engineering and technological limits. Any derived performance gaps and technology requirements simply took the form of some percentage improvement needed in familiar technologies. Generally, no insights into alternative technology approaches, such as from BTOs, were available.

Therefore, a useful methodology required that a higher-order, "technology-independent" parameter be defined. The parameter that serves this purpose is labeled an engineering assumption. Examination of the implicit assumptions uncovered in the HMs show them to be underlying engineering approaches based on traditional mission operations and functions, which of course are based on conventional systems capabilities and technology extrapolations.

Step 3 of the Methodology then, involves the identification of the Implicit Engineering Assumptions (IEAs) underlying the definition of the HMs and their requirements. Execution of this step should involve several people, perhaps in a workshop session, with the intent of uncovering as many IEAs are possible. Sources of the IEAs include: the mission scenario, the properties of the mission environment, the operational elements and system design choices, and the particular technology choices. The list of IEAs for an HM will characterize the traditional advanced mission design based on extrapolated conventional technological capabilities.

In Step 4, Alternative Engineering Assumptions (AEAs) are generated. Each of the IEAs may be challenged with one or more alternatives from which new system functions and technological capabilities are to be derived. A brainstorming session may be a useful approach here. But there is a caution - constraints (discussed in the next section) must be placed on the process to eliminate the "flake factor". Sources of AEAs include: specific emerging BTOs, scientific discoveries, new functional capabilities, integrative themes, and direct counter assumptions to the implicit assumptions.

The third stage of the Methodology is to return to the present to "Determine the Technology Requirements". In Step 5, all relevant BTOs are identified and evaluated for their ability to enable the AEAs. In fact, this will likely be an iterative process with new BTO capabilities stimulating still other AEAs. This step needs to be a thorough examination of all ways of using the several characteristics of each BTO. It should be expected that many of these "applications" of BTOs will seem fanciful and clearly impractical. But remember, the purpose of this step is to examine as many applications and relationships as possible. Techniques for performing this step include: examining all foreseeable uses of each BTO, examining extreme in-the-limit performance, and computer-based study of the parametric relationships involved in system optimization.

In Step 6, the evaluated BTOs are now screened for practicality and near-term relevance and priority. The criteria employed in this process will reflect the study objectives, policy directives, strategic requirements, investment strategies and programmatic needs. Technology requirements must then be determined for the resultant BTOs.

Establishing Horizon Missions

The primary requirement for Horizon Missions is that they be unreachable, that is, impossible to achieve with extrapolation of current technologies. However, they should not be so novel, their scope so vast or their driving motivation so far culturally from the present that it would impair serious consideration of the technology requirements. HMs or Horizon Capabilities should be "mainstream", that is, expected or at least candidate strategic extensions of the field several decades into the future. In fact, HMs might simply be constructed to answer the question: "What are the idealized missions or capabilities that will be the focus of your discipline, organization or market 10-50 years from now?".

The HMs must require a "quantum" leap in capability and/or performance in order to block extrapolation. The HMs must be impossible to achieve, otherwise no new creativity - problem statements or solution approaches - will occur. However, they should not require violation of the laws of physics.

For space technology a century of science fiction and nearly half a century of advanced space concept studies have provided many Horizon Missions to adapt. For other technology areas there may be no equivalent body of science fiction or visionary advanced concept studies and therefore HMs must be custom-built.

HMs may encompass a strategic or market goal or option; they may encompass functional requirements relating to current technology frontiers; in fact, they may be built around a single breakthrough technology. Used by a government organization, HMs may encompass their policies and strategic goals and may also represent future directions common to the broader non-government R&D community. For rapidly changing and highly competitive high technology industries, proprietary HMs might be generated and used internally for exploratory analysis of strategic options, specific research directions and alternative future contexts.

Using the Methodology

The HMM steps outside the usual pathways and boundaries of thinking. Therefore, using the HM Methodology requires mental discipline to "stay in character" and not revert to an extrapolation mentality with its conventional judgments of feasibility. This begins with the initial tendency to choose or create HMs that are more near-term and hence more "practical". Discipline must then be continued during Steps 1-4 to maintain the perspective that HMs are planning artifices, not missions to be flown, and are indeed relevant to today's problems of R&D choice.

Certainly the HMs should strategically encompass the dominant problems and issues of the present time - but they must leapfrog them. The place to address near-term relevance is in: 1) the functions selected for the HM, not in its time frame and 2) the final steps of the Methodology during which options will be evaluated and decision criteria and near-term investment strategies developed.

It is helpful at this point to take a broader look at what HMs and the HMM can do for conventional, (evolutionary rather than breakthrough) R&D planning and analysis (Fig. 2). In traditional planning for future missions and technologies we only "see" the future that is illuminated by "flashlight beams". These "beams" are single, unintegrated perceptions of the future confined to lie within our current technological paradigm and therefore representing linear extrapolations from the present. These "flashlight beams" show "what seems possible" in the future while standing on the platform of what we can do today.

However, it is certain that many future technology-related events will fall outside those "beams". While most of those events are unpredictable they can be grouped into classes. Three such classes are: breakthrough technology advances, combinations of conventional technology advances or capabilities, and future imposed requirements. Therefore, all conventional strategic and advanced R&D planning and analysis is deficient to the extent these event classes are not included.

The upper plane in Figure 2 represents all the future technological capabilities "we can conceive of", including those that arise from the classes of unpredictable events. It contains new capabilities not yet required by typical, extrapolative planning or not uncovered by linear projections of the state-of-the-art. The HM Methodology makes this future plane accessible for analysis by using Horizon Missions to provide encompassing overlays of integrated capability-requirements.

With this understanding, the HMs and HMM can support conventional, evolutionary R&D planning and analysis. Used for strategic planning HMs: 1) establish alternative frames of reference that can display the full range of what is conceivable in the future, not just what seems possible from the "flashlight beams" and 2) provide fixed strategic

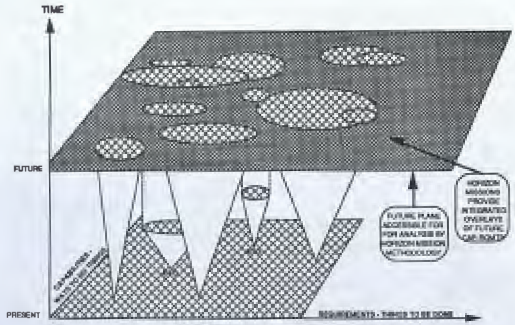

Figure 2. Technology Futures

references that are stable to compensate for a rapidly changing program environment or provide direction in the absence of strong, clear goals. Used for advanced design and analysis studies HMs: 1) provide "mission requirements" for breakthrough and disciplinary research, 2) help normalize contributions from diverse technology areas, and 3) provide templates for program planning and management with measurable, mission-oriented criteria ('metrics') for proposed or achieved progress. Used as an integrating mechanism HMs: 1) generate requirements for combinations of future capabilities, 2) exhibit the impact of embryonic technologies at the system level, and 3) create a common mission capturing key requirements of several technology areas.

HMs have an interesting potential for being a common currency for communication within an entire R&D community. Specifically, a HM would provide a common reference mission with a budget-independent structure and a user-specific substructure. "Common" because the HM can be chosen to represent a strategic horizon agreed to by an R&D community. "Reference mission" and "budget-independent" because the HM is hypothetical, unreachable, never intended to be built or flown and thus can be stable over time.

Vertical communication within an organization, from the CEO's vision to the managers' strategic and advanced program planning to the bench workers' creativity would be aided by the existence of HMs as a common focus. Horizontal communication for the space community could occur among government, industry and universities. Government agencies could infuse their policies and strategic goals in constructing HMs. The industry, in helping to configure HMs, would have a beyond-competition mission focus as a guide for its corporate strategies and independent R&D. But while subscribing to this common idealized HM, every industry member could create more specific HMs for internal use with near-term priorities and technology approaches shielded from view. The universities would have a mission focus endorsed by potential funding organizations for guiding their fundamental and applied academic research and planning.

Current Workshop/Studies

Each ongoing activity described below is a study centered about a workshop. The workshops, each serving a slightly different set of objectives, will be conducted between March and September 1994. Use of the HMM requires that the workshops be comprised of carefully chosen knowledgable, creative and adaptable people. Regarding the HMs it should be remembered that the purpose of these workshop/studies is to generate new concepts, perspectives, lines of thought, and frames of reference - not to validate the HM as a real future mission or to conduct engineering design or even conceptual design.

Advanced Biosensor Technology Development. The HMM is used to provide an integrating, systems-level mechanism for examining requirements and priorities for space biomedical and chemical sensors. The Horizon Capability (HC) chosen is an answer to the question "What will the stethoscope of 2025 look like?" The answer for this study is: a hand-held proximity detector of human or animal vital signs, providing non-invasive, immediate, quantitative multifunctional determination of homeostasis or pathology. This capability could closely resemble a Star Trek™ Tricorder™. A May 1994 workshop is scheduled. The HC provides a target and the HMM provides a referencable, structured approach for focusing a program with several functional categories and multiple technology options within each. As a first hardware step, a breadboard model of a handheld receiver for detecting signals from surface electrodes and implantable sensors is being built.

Space Exploration and Development (SE&D). The HMM is used to characterize the long-term (~2050) technological environment for robotic and human exploration and development of the solar system. The activity will identify future capabilities "required" for long-term SE&D, thereby providing an expanded range of options upon which to base strategic goals, advanced mission planning and technology prioritization. The Horizon Mission chosen is a Manned Jupiter Scientific Station that will research the entire Jovian system during the period 2045-2050. Two workshops will be conducted, one in March and one in June 1994. The second of these will begin to apply the insights gained through the HMM to specific near-term advanced missions, to establish a core of people who have learned to apply this new way of thinking to technology and mission planning and to identify strategies for utilizing this core and expanding it throughout the SE&D community.

Trimarket Space Carrier Industry. The HMM is used to provide an integrating strategic vision of a fully commercial space carrier industry. This vision will be used to initially define the capabilities, requirements and technological path-ways leading to the creation and growth of such an industry that would enable an orbital economy in 2045. The Horizon Mission is a fully commercial trimarket space carrier capability (earth-to-orbit, highest speed transglobal, and cislunar transport, infrastructure of ground and space ports, polar-orbiting and plane-changing capabilities) - an air carrier analog. The activities will create a common, self-consistent strategic reference mission scenario for planning use by the broad relevant R&D community.

Ultratechnology Astrophysics Capabilities. The HMM is used to define a set of ultra-advanced capabilities and technology requirements that would be common to a broad class of astrophysics missions 20-50 years hence, under the uncertainty of what the important scientific questions will be at that time. Two Horizon Missions are being considered. One is a heliocentric (polar orbiting) set of satellites providing a very large aperture receiver at 1-5 AU for 10 years for out-of-the-ecliptic observations and solar tomography. The other is a 2 AU baseline interferometric gravity wave detector. A Science Advisory Team will assist in formulating the HMs and conducting the workshop.

Advanced Aeronautics Technology. The HMM is used to implement a conceptual systems approach (future "required" capabilities) for use in strategic planning of basic technology research to provide revolutionary aeronautics capabilities in 10-20 years and to provide a basis for planning and advocacy of the basic aeronautics technology program in terms of its relevancy to the needs of the industry. An example Aeronautics Horizon (Mission) is an Ultimate Subsonic Aircraft with: external noise below background: zero NO_x, soot, CO and HC; all weather, full runway capacity operations; no unscheduled maintenance; maintenance common among all; autonomous, common cockpit; one size expandable to fit all capacities and ranges. Two workshops will be conducted in late summer 1994, the first to allow industry representatives at the VP level to construct the appropriate HMs.

Concluding Remarks

The HMM was begun for the specific purpose of evaluating space breakthrough perspectives and technology options. However, it has become evident from this work in progress and the beginnings of other applications that the HMM has enormous versatility. This versatility implies a powerful new tool that taps into fundamental human traits of creativity and inventiveness in a different way.

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The power of Horizon Missions lies in their being deliberately chosen to be impossible - unreachable by linear technology extrapolation. Their relevance lies in choosing them to be strategically relevant and in the Methodology steps which provide the way back from the future to near-term issues and decisions. Because the HMM involves a new form of thinking, considerable discipline is required in using it, to maintain a perspective from the future.

Using future, impossible missions to guide today's pragmatic R&D decisions on technology research is clearly a new paradigm. The HM Methodology is the guideway that allows a user to think and stay within this new paradigm.

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