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NTP Comparison Process

Nuclear Propulsion Technical Interchange Meeting

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Robert Corban
Nuclear Propulsion Office
NASA Lewis Research Center

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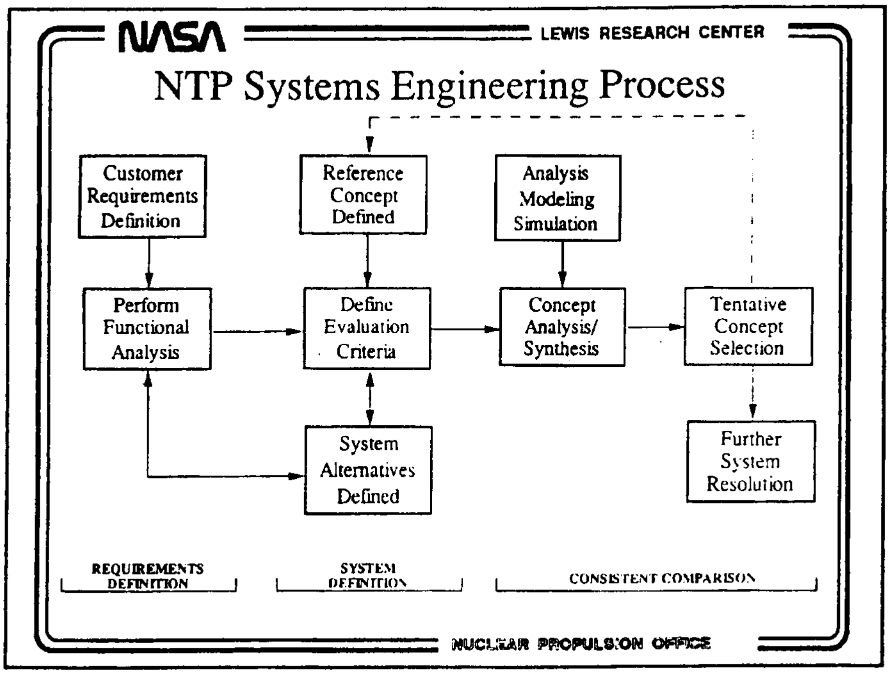

NTP Systems Engineering Process

The systems engineering process is shown above is for the concept definition phase of the program. The process involves three major elements: requirements definition, system definition, and consistent concept comparison. The requirements definition process involves obtaining a complete understanding of the system requirements based on customer needs, mission scenarios, and NTP operating characteristics. A system functional analysis is performed to provide a comprehensive traceability and verification of top-level requirements down to detailed system specifications and provides significant insight into the measures of system effectiveness to be utilized in system evaluation. The second key element in the process is the definition of system concepts to meet the requirements. This part of the process involves engine system and reactor contractor teams to develop alternative NTP system concepts that can be evaluated against specific attributes, as well as a reference configuration against which to compare system benefits and merits. Establishing the evaluation criteria will be extremely challenging and critical to the entire evaluation and selection process. Due to the various disciplines required and many goals the system will be required to achieve, an iterative and participative team approach must be utilized. Various methodologies exist for evaluating a comprehensive set of evaluation criteria: analytic hierarchy process (AHP), multiple-attribute-utility method (MAUM), and weighted-outranking method (WOM), but these provide little structure in identifying the key criteria. Quality function deployment (QFD), as an excellent tool within Total Quality Management (TQM) techniques, can provide the required structure and provide a link to the "voice" of the customer in establishing critical system qualities and their relationships. The third element of the process is the consistent performance comparison. The comparison process involves validating developed concept data and quantifying system merits through analysis, computer modeling, simulation, and, if required, rapid prototyping of the proposed high risk NTP subsystems. The maximum amount possible of quantitative data will be developed and/or validated to be utilized in the QFD evaluation matrix. If upon evaluation of a new concept or its associated subsystems determine to have substantial merit, those features will be incorporated into the reference configuration for subsequent system definition and comparison efforts.

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Requirements Definition

- **Customers**
  - Understand who are our customers
  - Need to understand customer needs & priorities
- **Functional Analysis**
  - AEC selected to provide requirements management
    - RDD-100 Systems Engineering Software
    - Functional hierarchy being developed
    - Requirements traceability & verification
  - "Living" Requirements Document established

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Requirements Definition

Customer

A critical element of the process is the identification of the "customer(s)" and their particular desires for the NTP system. Those customers will consist of the President, Congress, the Nation's taxpayers, NASA management, and other government agencies concerned with the systems development and usage. These customers will most likely have different goals and objectives that must be understood and satisfied. The "voice" of the customers will be required to be part of the requirements definition process to guarantee their requirements are factored into the system.

NTP Requirements

The current top-level requirements for NTP for meeting currently envisioned SEI missions for cargo and piloted Mars missions have been in development over the past two years. A "living" requirements document has been developed with an on-going review process that incorporates current NTP team revisions and suggestions and begins to obtain a complete customer "voice" in the process. The current requirements have been incorporated by Analytical Engineering Corporation (AEC) into Ascent Logic's powerful systems engineering software the Requirements Driven Development (RDD™) System Designer. This will allow for functional analysis, traceability, component-to-functions mapping, model behavior analysis, and failure propagation analysis.

Functional Analysis

AEC will be employing a methodology known as Enhanced Modern Structured Analysis (EMSA) in the analysis of the NTP systems. It will permit a logical structuring of all system functions in a top-down hierarchical decomposition to draw out all the requirements the system must meet while also providing insight for the system-level model developers and technologists. Various options will be provided to display the logical sequences and relationships of operational and support functions that lead to the fulfillment of each NTP function. Time dependent functions will be coupled with behavior models to allow for time-critical functional analysis. This analysis will also develop the basis for establishing functional interfaces and identify system relationships required in meeting SEI mission goals.

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System Definition

- **NTP System Alternatives**
  - Initial database developed on four concepts
  - Date developed based on consistent requirements
- **Reference Concept**
  - Quantify alternative concept benefits
    - Risk - Cost - Schedule - Performance
  - NERVA-derived initial reference due to significant database
- **Evaluation Criteria**
  - Must focus on customer needs
  - Participative approach
  - Utilize Quality Functional Deployment (QFD)
    - TQM tool • Structured & Systematic
    - Expanded usage possible for later program phases

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System Definition

NTP System Alternatives

Efforts were funded in 1992 by NASA to develop consistent state-of-the-art NTP concept data based on the same mission and engine requirements to permit an apples-to-apples comparison. Four alternative concepts were examined by various contractors to evaluate concept feasibility, thrust level implications in the range of 25,000 to 75,000 lbf, test facility requirements, manned mission impacts, key component technologies required, and an industrial approach to developing the system within the next decade. The four concepts examined were each defined based on a specific nuclear fuel element concept consisting of NERVA - derived, CERMET, Particle Bed, and a "twisted-ribbon" fuel element developed by the CIS.

Reference Concept

A reference concept will be utilized to help determine quantitative benefits of alternative engine concepts or subsystem. Significant past efforts on the NERVA concept combined with well understood improvements makes the current NERVA-derived concept the logical choice for the initial reference engine. The use of a reference concept will help in determining the benefits of alternative approaches to better quantify the risk, cost, performance, and schedule impacts.

System Attributes

The process required for evaluation and selection of a single NTP concept must be able to provide a structure that encourages the participation of many various disciplines and provides a focus on the customer needs. The attributes will not be honored if they are not obtained in a participative manner. Quality Functional Deployment, also referredto as the "house of quality," has demonstrated an advantage in providing a systematic and structured approach to achieving high quality systems. QFD identifies the most important system characteristics, relates characteristics directly to requirements, and identifies which characteristics need to be controlled. The current process will concentrate on only providing a system attributes matrix for NTP concept evaluation due to the extensive training, "cultural shock," and laborious nature in implementing QFD. But, with the goal within NASA to provide "faster, better, and cheaper" systems through Total Quality Management (TQM), the initial use of QFD can be expanded to provide the discipline required to achieve this ambitious goal.

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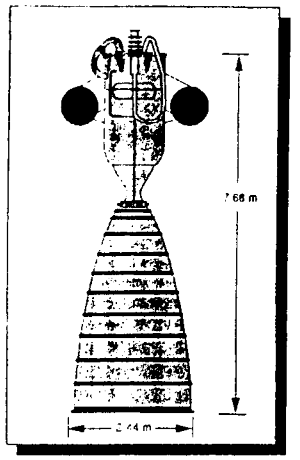
Reference NTP Engine



Characteristics

Flow Cycle	Expander
Fuel Form	Composite (NERVA)
Thrust (lbf)	50,000
Chamber Temperature (K)	2700 (4860 °R)
Chamber Pressure (psia)	785
Nozzle Expansion Ratio	200:1
Specific Impulse (sec)	900
Mass (kg)*	5237
Thrust/Weight	4.3

* Dual Turbopump w/ internal shielding mass (560 kg)

Key Features

- Proven Technology --> Low Risk Approach
- Optimized Engine packaging/nozzle design for maximum Isp
- Optimized flow balance to minimize pressure/weights

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Reference NTP Engine

The reference NTP concept shown above was defined by the Rocketdyne/Westinghouse team. The reference concept is based on a 50,000 pound engine utilizing dual turbopumps, 200:1 nozzle expansion and composite fuel within the NERVA fuel element configuration operating at 2700 K and a 785 psi chamber pressure. This NERVA reference engine shown is preliminary at this point. An initial reference engine and associated database will be determined in the next few months.

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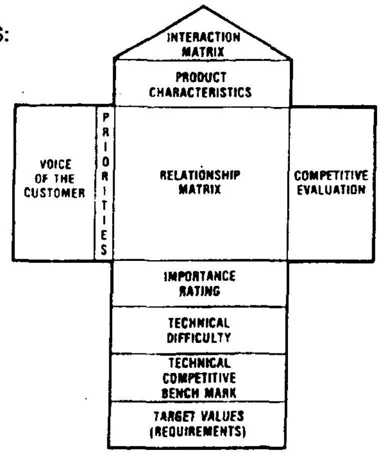
QFD Benefits

THE HOUSE OF QUALITY PROVIDES:

- A REQUIREMENTS PLANNING CAPABILITY
- A TOOL FOR GRAPHIC AND INTEGRATED THINKING
- A MEANS TO CAPTURE AND PRESERVE THE ENGINEERING THOUGHT PROCESS
- A MEANS TO COMMUNICATE THE THOUGHT PROCESS TO NEW MEMBERS OF THE QFD TEAM
- A MEANS TO INFORM MANAGEMENT REGARDING INCONSISTENCIES BETWEEN REQUIREMENTS, RISKS AND NEEDS OF THE CUSTOMER



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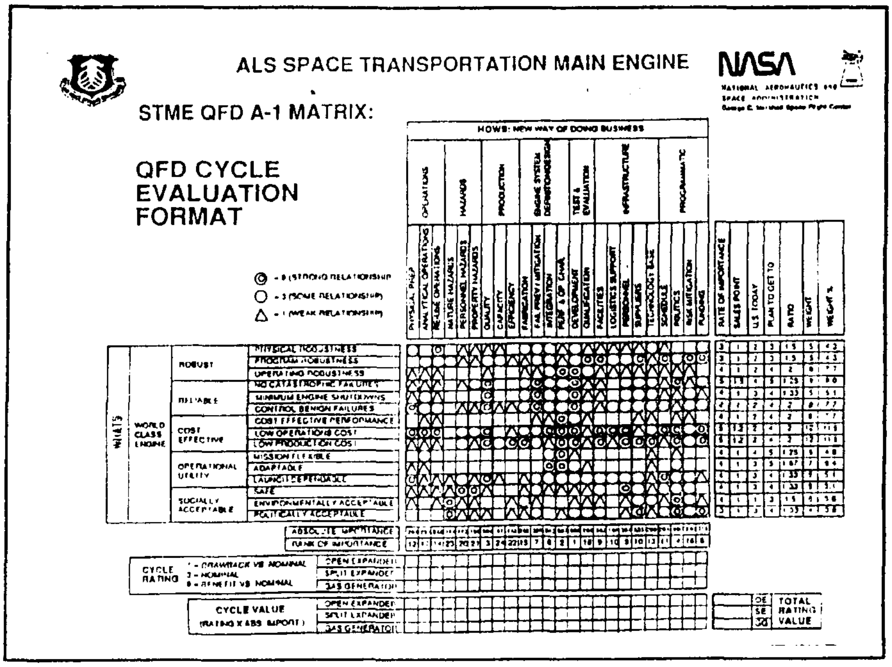
QFD Benefits

QFD was developed in Japan in the late 1960's in response to a recognized lack of "quality" in the definition/design process. The foundation for QFD is in the belief that systems should be designed to reflect customer needs and desires, thus requiring all disciplines to work closely together from the time a system is first conceived. Quality Functional Deployment, also referred to as the "house of quality," has demonstrated an advantage in providing a systematic and structured approach to achieving high quality systems. QFD identifies the most important system characteristics, relates characteristics directly to requirements, and identifies which characteristics need to be controlled. QFD provides a significant number of benefits in obtaining a quality product. Some of those benefits are shown above.



QFD Evaluation Matrix Example

The QFD matrix, as shown in the example developed in the space transportation main engine (STME) program, begins with the customer needs, or wants, in phrases that describe the system and its characteristics in their own words. The wants are often grouped into areas of overall customer concerns that typically can include primary, secondary, and tertiary levels. Not all preferences are equal and the customer's needs must be weighted based on discussions with the customers. The top of the QFD matrix lists those engineering characteristics that are likely to affect one or more of the customer needs. These characteristics should describe the system in measurable terms. The body of the matrix is filled with symbols indicating the strength of the customer needs in relationship with the engineering characteristics. On the right-hand side of the matrix, current reference concept's level of meeting customer expectation and opportunities for improvement are determined. The rating of customer needs along with the number and strength of the matrix relationships provides the weighting for the engineering characteristics.

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Consistent Comparison

- **Integrated Government Team Formed**
  - Develop & implement system performance modeling
  - State-of-the-art computational techniques
- **Provide and/or Verify Quantitative Data**
- **Perform Risk and Failure Analysis**
- **Utilize Established Government Cost Models**

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Consistent Comparison

The consistent comparison element of the process must provide and/or verify the quantitative data upon which the concepts will be evaluated. This data must be based on consistent assumptions, groundrules, and requirements. The data provided must also be independently verified to ensure proper analysis has been completed. The fundamental tools that assist the systems engineer in this process are the system performance and cost models, and quantitative risk assessments.

An integrated Government team has been formed to develop and implement a strategy for modeling NTP system performance. The modeling team was formed in order to integrate state-of-the-art computational resources and techniques, along with a diverse knowledge base, into simulations of NTP system performance. A parametric NTP model will be used to predict the system performance for all defined NTP concepts on a consistent basis. The model will also provide steady-state performance data for use in SEI mission analysis and evaluate system design perturbations. Transient evaluations, such as start-up and shut-down, will also be performed as the data and models become available. This will provide a means to evaluate the quantitative benefits to the system based on proposed subsystem and component improvements.

Risk, schedule, and cost analysis will be performed in addition to the performance assessments. The RDD™-100 systems engineering tool will be coupled with the Failure Environment Analysis Tool (FEAT) to assist in the identification of hardware and software failure effects on the entire system. This will ensure that the concept complies to redundancy, reliability, and safety requirements. Cost analysis will utilize established Government cost models to quantify cost benefits to the system upon the implementation of an alternative.