Engineering Design

2.1 What is: The **engineering design process** is the formulation of a plan to help an engineer build a product with a specified performance goal. This process involves a number of steps, and parts of the process may need to be repeated many times before production of a final product can begin.

The engineering design process is a multi-step process including the research, conceptualization, feasibility assessment, establishing design requirements, preliminary design, detailed design, production planning and tool design, and finally production. The sections to follow are not necessarily steps in the engineering design process, for some tasks are completed at the same time as other tasks. This is just a general summary of each part of the engineering design process.

Research A significant amount of time is spent on research, or locating information. Consideration should be given to the existing applicable literature, problems and successes associated with existing solutions, costs, and marketplace needs. The source of information should be relevant, including existing solutions. Reverse engineering can be an effective technique if other solutions are available on the market. Other sources of information include the Internet, local libraries, available government documents, personal organizations, trade journals, vendor catalogs and individual experts available.

Conceptualization

Once an engineering issue is defined, solutions must be identified. These solutions can be found by using ideation, or the mental process by which ideas are generated. The following are the most widely used techniques:

- trigger word - a word or phrase associated with the issue at hand is stated, and subsequent words and phrases are evoked. For example, to *move* something from one place to another may evoke *run*, *swim*, *roll*, etc.
- morphological chart - independent design characteristics are listed in a chart, and different engineering solutions are proposed for each solution. Normally, a preliminary sketch and short report accompany the morphological chart.
- synectics - the engineer imagines him or herself as the item and asks, "What would I do if I were the system?" This unconventional method of thinking may find a solution to the problem at hand.the vital aspects of the

conceptualization step is synthesis. Synthesis is the process of taking the element of the concept and arranging them in the proper way. Synthesis creative process is present in every design.

- brainstorming - this popular method involves thinking of different ideas, typically as part of a small group, and adopting these ideas in some form as a solution to the problem

Feasibility assessment The purpose of a feasibility assessment is to determine whether the engineer's project can proceed into the design phase. This is based on two criteria: the project needs to be based on an achievable idea, and it needs to be within cost constraints. It is important to have an engineer with experience and good judgment to be involved in this portion of the feasibility study.

Establishing the design requirementsEstablishing design requirements is one of the most important elements in the design process,[4] and this task is normally performed at the same time as and the feasibility analysis. The design requirements control the design of the project throughout the engineering design process. Some design requirements include hardware and software parameters, maintainability, availability, and testability.

Preliminary design

The preliminary design, or high-level design, bridges the gap between the design concept and the detailed design phase. In this task, the overall system configuration is defined, and schematics, diagrams, and layouts of the project will provide early project configuration. During detailed design and optimization, the parameters of the part being created will change, but the preliminary design focuses on creating the general framework to build the project on.

Detailed design

The detailed or low-level design portion of the engineering design process is the task where the engineer can completely describe a product through solid modeling and drawings. Some specifications include:

- Operating parameters
- Operating and nonoperating environmental stimuli
- Test requirements
- External dimensions
- Maintenance and testability provisions
- Materials requirements

- Reliability requirements
- External surface treatment
- Design life
- Packaging requirements
- External marking
- input machine

The advancement of computer-aided design, or CAD, programs have made the detailed design phase more efficient. This is because a CAD program can provide optimization, where it can reduce volume without hindering the part's quality. It can also calculate stress and displacement using the finite element method to determine stresses throughout the part. It is the engineer's responsibility to determine whether these stresses and displacements are allowable, so the part is safe.

Production planning and tool design

The production planning and tool design is nothing more than planning how to mass-produce the project and which tools should be used in the manufacturing of the part. Tasks to complete in this step include selecting the material, selection of the production processes, determination of the sequence of operations, and selection of tools, such as jigs, fixtures, and tooling. This task also involves testing a working prototype to ensure the created part meets qualification standards.

Production

With the completion of qualification testing and prototype testing, the engineering design process is finalized. The part must now be manufactured, and the machines must be inspected regularly to make sure that they do not break down and slow production.

2.2 Design engineer

Design Engineer is a general term that covers multiple engineering disciplines including electrical, mechanical, chemical engineer, aeronautical engineer, civil, and structural/building/architectural engineers. The uniting concept is a focus on applying the 'engineering design process, *in which engineers develop new products or processes with a primary emphasis on functional utility*.

While industrial designers may be responsible for the conceptual aesthetic and ergonomic aspects of a design, the design engineer usually works with a team of engineers and other designers to develop conceptual and detailed designs. He may work with industrial designers and marketers to develop the product concept and specifications, and may direct the design effort. In many engineering areas, a distinction is made between the design engineer and the planning engineer in design; Analysis is important for planning engineers, while synthesis is more paramount for design engineers. Test engineers are also sometimes contrasted from design engineers, as test engineers tend to focus more on the evaluation and analysis of prototypes (rather than their conception).

When the design involves public safety, the design engineer is usually required to be licensed, for example a Professional Engineer in the U.S and Canada. There is usually an 'industrial exemption' for design engineers working on project internal to companies and not delivering professional services directly to the public.

Design engineer tasks

They may work in a team along with industrial designers to create the drawings necessary for prototyping and production, or in the case of buildings, for construction. However, with the advent of CAD and solid modeling software (PTC Creo, SolidWorks, SpaceClaim, Solid Edge, KeyCreator Autodesk Inventor, boss, NX, CATIA, etc., for example) the design engineers may create the drawings themselves.

The next responsibility of many design engineers is prototyping. A model of the product is created and reviewed. Prototypes are either functional or non-functional. Functional "alpha" prototypes are used for testing and the non-functional are used for form and fit checking. Virtual prototyping software like Ansys or Comsol may also be used. This stage is where design flaws are found and corrected, and tooling, manufacturing fixtures, and packaging are developed.

Once the "alpha" prototype is finalized, after many iterations, the next step is the "beta" pre-production prototype. The design engineer, working with a industrial engineer and manufacturing engineer and a quality engineer reviews an initial run of components and assemblies for design compliance and fabrication/manufacturing methods analysis. This is often determined through statistical process control. Variations in the product are correlated to aspects of the process and eliminated. The most common metric used is the process capability index.

The design engineer may follow the product and make requested changes and corrections throughout the life of the product. This is referred to as "cradle to grave" engineering.

The design process is an information intensive one and design engineers have been found to spend 56% of their time engaged in various information behaviours, including 14% actively searching for information. Furthermore, in addition to design engineers' core technical competence, research has also demonstrated the critical nature of their personal attributes, project management skills, and cognitive abilities to succeed in the role.

Amongst other more detailed findings, a recent work sampling study found that design engineers spend 62.92% of their time engaged in technical work, 40.37% in social work, and 49.66% in computer-based work. Furthermore, there was considerable overlap between these different types of work, with engineers spending 24.96% of their time engaged in technical and social work, 37.97% in technical and non-social, 15.42% in non-technical and social, and 21.66% in non-technical and non-social.

2.3 Design review

A **design review** is a milestone within a product development process whereby a design is evaluated against its requirements in order to verify the outcomes of previous activities and identify issues before committing to - and if need to be re-prioritise - further work. The ultimate design review, if successful, therefore triggers the product launch or product release.

The conduct of design reviews is compulsory as part of design controls, when developing products in certain regulated contexts such as medical devices.

By definition, a review must include persons who are external to the design team.

Contents of a design review

In order to evaluate a design against its requirements, a number of means may be considered, such as:

- Physical tests.
- Engineering simulations.
- Examinations (Walk-through).

Timing of design reviews

Most formalised systems engineering processes recognise that the cost of correcting a fault increases as it progresses through the development process. Additional effort spent in the early stages of development to discover and correct errors is therefore likely to be worthwhile. Design reviews are an example of such an effort. Therefore, a number of design reviews may be carried out, for example to evaluate the design against different sets of criteria (consistency, usability, ease of localisation, environmental) or during various stages of the design process.

Design review (U.S. government)

In the United States military integrated acquisition lifecycle the Technical section has multiple acquisition "Technical Reviews". Technical reviews and audits assist the acquisition and the number and types are tailored to the acquisition. Overall guidance flows from the Defense Acquisition Guidebook chapter 4, with local details further defined by the review organizations. Typical topics examined include adequacy of program/contract metrics, proper staffing, risks, budget, and schedule.

In NASA's engineering design life cycle, a phase of **design reviews** are held for technical and programmatic accountability and to authorize the release of funding to a project. This article describes the major phases of that systems engineering process. A design review provides an in-depth assessment, by an independent team of discipline experts and managers, that the design (or concept) is realistic and attainable from a programmatic and technical sense.

Design review is also required of medical device developers as part of a system of design controls described in the US Food and Drug Administration's governing regulations in 21CFR820. In 21CFR820.3(h), design review is described as " documented, comprehensive, systematic examination of the design to evaluate the adequacy of the design requirements, to evaluate the capability of the design to meet these requirements, and to identify problems." The FDA also specifies that a design review should include an independent reviewer.

Review process

The list of reviews done by an effort and the content, nature, process, and objectives any review uses vary enormously by the organization involved and the particular situation of the effort. For example, even within the U.S. Department of Defense, System Requirements Review cases include such as (1) a 5 day perusal of each individual requirement, or (2) a 2-day discussion of development plan documents allowed only after the system requirements have been approved and the development documents reviewed with formal action items required, or (3) a half-day powerpoint with content determined by the Project Manager with attendance limited to high-level (non-technical) stakeholders with no output other than the PM being able to claim 'SRR done'.

Some of the reviews that may be done on an effort include:

Mission Concept Review (MCR) The MCR affirms the mission need and examines the proposed mission's objectives and the concept for meeting those objectives.

System Requirements Review (SRR) The SRR examines the functional requirements and performance requirements defined for the system and the preliminary program or project plan and ensures that the requirements and the selected concept will satisfy the mission.

Mission Definition Review (MDR) The MDR examines the proposed requirements, the mission architecture, and the flow down to all functional elements of the mission to ensure that the overall concept is complete, feasible, and consistent with available resources.

System Design Review (SDR) The SDR examines the proposed system architecture and design and the flow down to all functional elements of the system.

Preliminary Design Review (PDR) The PDR demonstrates that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design. It will show that the correct design options have been selected, interfaces have been identified, and verification methods have been described.

The following are typical objectives of a PDR:

- Ensure that all system requirements have been allocated, the requirements are complete, and the flowdown is adequate to verify system performance
- Show that the proposed design is expected to meet the functional and performance requirements
- Show sufficient maturity in the proposed design approach to proceed to final design

- Show that the design is verifiable and that the risks have been identified, characterized, and mitigated where appropriate

Critical Design Review (CDR)

The CDR demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test. CDR determines that the technical effort is on track to complete the flight and ground system development and mission operations, meeting mission performance requirements within the identified cost and schedule constraints.

The following are typical objectives of a CDR:

- Ensure that the "build-to" baseline contains detailed hardware and software specifications that can meet functional and performance requirements
- Ensure that the design has been satisfactorily audited by production, verification, operations, and other specialty engineering organizations
- Ensure that the production processes and controls are sufficient to proceed to the fabrication stage
- Establish that planned Quality Assurance (QA) activities will establish perceptive verification and screening processes for producing a quality product
- Verify that the final design fulfills the specifications established at PDR

Production Readiness Review (PRR)

A PRR is held for Flight System and Ground Support projects developing or acquiring multiple or similar systems greater than three or as determined by the project. The PRR determines the readiness of the system developers to efficiently produce the required number of systems. It ensures that the production plans; fabrication, assembly, and integration enabling products; and personnel are in place and ready to begin production.

Test Readiness Review (TRR)

A TRR ensures that the test article (hardware/software), test facility, support personnel, and test procedures are ready for testing and data acquisition, reduction, and control. This is not a prerequisite for KDP E.

System Acceptance Review (SAR)

The SAR verifies the completeness of the specific end products in relation to their expected maturity level and assesses compliance to stakeholder expectations. The SAR examines the system, its end products and documentation, and test data and analyses that support verification. It also ensures that the system has sufficient technical maturity to authorize its shipment to the designated operational facility or launch site.

Operational Readiness Review (ORR)

The ORR examines the actual system characteristics and the procedures used in the system or end product's operation and ensures that all system and support (flight and ground) hardware, software, personnel, procedures, and user documentation accurately reflect the deployed state of the system.

The following are typical objectives of an ORR:

- Establish that the system is ready to transition into an operational mode through examination of available ground and flight test results, analyses, and operational demonstrations
- Confirm that the system is operationally and logistically supported in a satisfactory manner considering all modes of operation and support (normal, contingency, and unplanned)
- Establish that operational documentation is complete and represents the system configuration and its planned modes of operation
- Establish that the training function is in place and has demonstrated capability to support all aspects of system maintenance, preparation, operation, and recovery.