Exploratory Design Methods and Techniques in Support of Space Mission Concept Development

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Submitted to the Program in Media Arts and Sciences,
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ABSTRACT I Designers are ubiquitous in the Consumer Product Industry, the Automotive Industry and Entertainment. Fields such as Product Design, Transportation Design and Entertainment Design emphasize finding solutions to problems using Exploratory Design Methods and Techniques. However, there is not a direct appreciation or understanding of how to utilize these Methods and Techniques within Aerospace.

This thesis explores opportunities within the Space Mission Concept Development process where exploratory design methods and techniques may be supportive, and where these techniques are currently used. The work develops a design library of Methods and Techniques used outside of Aerospace that may help teams reach the goals of Space Mission Design defined by the milestones within the NASA Flight Mission Lifecycle. The thesis analyses Exploratory Design Methods used in other industries, such as Design Thinking, Human Centered Design, Imagineering and Science Fiction Thinking and shows how these methods can be subdivided into a common set of techniques, such as Storyboarding, Sketching and Prototyping. Interviews with employees within Aerospace and the Consumer Product Industry may shed light on opportunities and barriers to utilizing these Techniques.

This thesis hopes to fill a gap in literature by framing the current state of Exploratory Design Methods and Techniques within Space Mission Development and laying the groundwork to begin utilizing a wider variety of Design Methods and accompanying Techniques. This thesis also contributes to documenting the roles that Designers have played in the Aerospace Industry throughout its history and argues for the benefits of including Design professionals within Aerospace teams as valued contributors.

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Glossary of Key Terms

3D Modeling	A form of computer graphics development that allows for an object to be rendered in three dimensions.
Achievable Futures	Ideation of an achievable scope of cost constraints in space mission Formulation.
Advertising	A branch of Design focusing on marketing of products and services.
Aerospace Engineering	A branch of Engineering focusing on design, development and production of spacecraft and related systems.
Aerospace Industry	A business area concerning science and Engineering focusing on Earth's atmosphere and surrounding space.
Aesthetics	A branch of philosophy dealing with beauty in Art.
Animation	A process through which objects are manipulated to move, often hand drawn or 3D rendered.
Apparel Industry	The business and making and selling clothing.
Architect	An individual that works to Design buildings.
Art	The act of Imagination, creative skill and works appreciated primarily for beauty and emotional power.
Art Center College of Design	A leading Industrial Design Institution in Pasadena, California http://www.Artcenter.edu/
Artist in Residence	An institutional program meant for an Artist to reside within the premises to develop works of Art.
Arts and Crafts	Activities involved in decorative Designs and handcrafted goods.
Assigned Missions	Flight Projects given to NASA Field Centers for management and implementation.
Attraction	A ride, environment or space meant for entertainment within a theme park.
Audience	Spectators and visitors of a film, concert, play, or other event.
Automotive Industry	A business area concerning the Design and manufacturing of vehicles.
Bauhaus	An influential German Art school in the early 1900's that unified Art and manufacturing.

Bauhaus Center Tel Aviv	An Institution whose goal it is "to expand public recognition of "White City" as a unique architectural and cultural site.": https://www.bauhaus-center.com/about/
Bezalel academy of Arts and Design Jerusalem	A leading Institution for design in Jerusalem. http://www.bezalel.ac.il/en/
Characters	An individual in a movie, play, film or other narrative.
China Academy of Art	A Fine Art college under the direct charge of the Ministry of Culture of China. https://en.caa.edu.cn/
Co-Design	This term refers to planning and problem solving collaboratively with clients, stakeholders and individuals involved in finding the solution to a challenge.
Collaging	A combination or collection of photographs that are pieced together.
Color Theory	This term refers to guidelines on the use of color in Art and Design Disciplines.
Communication	The conveying of information or news.
Competed Missions	Various parties, often NASA Field Centers and other institutions propose detailed concepts to be selected as a mission by a committee of reviewers.
Computational Art	Art that uses technology as the main medium.
Concept Design	The development of an initial idea, often illustrated for visual aid and communication with clients.
Concept Maturity Levels (CMLs)	A categorization system developed at the Jet Propulsion laboratory through which a space mission concept can be communicated and scoped.
Concept of Operations (ConOps)	a document within the NASA Flight Mission Lifecycle outlining leadership's expected process for implementing a project.
Constructivism	This Artistic philosophy rejects aesthetic stylization, while instead leveraging the industrial assembly of materials.
Consumer Product Industry	The business of manufacturing and selling objects that will be used by individuals, such as home décor and electronics.
Creativity	The ability to make connections between two seemingly unrelated objects or experiences.
Crewed Missions	Space missions that involve human passengers.
Critical Design Review (CDR)	A review within the NASA Flight Mission Lifecycle that demonstrates maturity of a Design, in support

	of full-scale fabrication, assembly, integration and testing.
Design	A plan for the development of an object or system.
Design Analysis Cycle	This Is an Engineering Method of applying ongoing evaluation tasks to existing projects.
Design Education	An education from a Design school with foundations in Color Theory, Shape Language and Modernism.
Design Institution	A college, influential organization or other establishment founded for advancement of the Design practice.
Design Method	An approach used by the Designers for clarity of work, organization of ideas and problem solving.
Design Teams	Groups comprised of individuals with a Design Education.
Design Techniques	This term refers to skills utilized by Designers in their work, such as Sketching Prototyping and Storyboarding.
Design Thinking	A non-linear Method of problem solving used by Designers for solving problems.
Discipline	A branch of knowledge, typically studied in higher education.
Drawing	A visual or graphical image, created with pencil, pen marker or digital mediums.
Electrical Engineer	A branch of Engineering dealing with study, Design and fabrication of electrical systems.
Engineering	A branch of science and technology focusing on Design and Manufacturing of machinery and structures.
Engineering Education	The study of a branch of Engineering.
Entertainment Industry	The business associated with providing joy and amusement. This includes television, concerts, Feature Film, video games and theme parks.
Exploratory Methods	Problem solving processes used by Designers.
Fashion Design	The branch of Design focusing on clothing manufacturing and Style.
Feature Film	A motion picture with a running time long enough to be considered enough to fill a program.
Flight Projects	A defined time- and cost- controlled program intended for launch into space.
Flight Readiness Review (FRR)	This review within the NASA Flight Mission Lifecycle determines the readiness of a project to begin tests or Operations.

Formulation	This set of phases in the NASA Flight Mission Lifecycle are intended to develop project requirements while considering cost/schedule.
Harvard Graduate School of Design	A graduate program at Harvard focusing on the Design practice. https://www.gsd.harvard.edu/
Human Centered Design	A Design Method that begins with involving the human perspective.
Human Factors	The application of phycological and physiological principles to Engineering.
Human Habitation	NASA projects that involve humans interacting with Engineered environments.
Human Spacecraft Design	The project planning for space mission Architectures that involve humans.
Human-Computer Interaction	The study of the Design and interfaces between humans and computers.
Idea Generation	The production of concepts and information.
IIT Institute of Design	A graduate school founded as "The New Bauhaus" in Chicago, Illinois. https://id.iit.edu/
Illustration Design	A branch of Design dealing with drawn imagery for a specific use, such as for magazines, journals and print.
Imagination	The action of forming new ideas and concepts that do not exist yet to the senses.
Imagineer	The career title of employees at The Walt Disney Company that develop theme parks. Specialties in disciplines are not distinguished.
Industrial Design	A branch of Design that is applied to product development.
Industrial Design Research	This term refers to information gathering methods used by Industrial Designers on user behavior.
Information Design	A branch of Design specializing in portrayal on information for efficiency.
Innovation	Development of a new Method or idea.
Installation Art	Artwork that contains a variety of media, including sound, video performance and virtual reality. This genre is meant to transform spaces and can be temporary or permanent.
Instruments	A device used for scientific purposes. For this thesis, the term means custom hardware for space missions.
Key Decision Points (KDPs)	The events within the NASA Flight Mission Lifecycle at which decision makers determine the readiness of programs to progress into the next phase of the lifecycle.

Launch Vehicle	This term refers to large carrier rockets that carry spacecraft to space.
Matte Painting	Matte Painting is a Technique used by Concept Designers to create landscapes and environments through Photography manipulation and digital illustration.
Mechanical Engineering	A branch of Engineering dealing with development and construction of machines.
Medium	This term refers to materials used by Artists when creating Artwork.
Melbourne School of Design	A Graduate School within the University of Melbourne in Australia that focuses on the Design practice. https://msd.unimelb.edu.au/
Mission Concept Development	The process of advancing a space mission project idea through the initial phases of the NASA Flight Mission Lifecycle.
Model Making	The creation of an object, often with a high level of detail at varying scales of size. Used as prototypes or for communication purposes.
Modernism	A movement in the Arts towards minimalism and in opposition of decorated styles.
Motion Graphics Design	A branch of Design focusing on motion of Typography and objects.
NASA Art Program	A program within NASA that invites Artists to participate in events and launches for creation of Artwork. Today, it supports Artists who intend to use the NASA logo or history in their Artwork.
NASA Field Centers	NASA facilities that specialize in a variety of areas, such as astrophysics, heliophysics, aviation, Planetary Science and development of technology.
Netherland's Design Institute	A former Institute for advancement of Design in Kierzersgracht, Amsterdam. https://rkd.nl/nl/explore/collections/733
Object-Process Methodology (OPM)	A system Engineering Method of capturing knowledge based on "two main components: elements/process and process/feature"
Observation	Gaining awareness of the customer as they use a current product, or navigate through a system.
Operations	This term describes technical activities after a space project has launched.
Outreach	Within NASA this means providing scientific information to the public about space mission findings.

Painting	The process of creating an image using pigments on a surface, usually a canvas.
Photograpy	Producing images through use of a camera.
Planetary Science	The scientific study of planets and planetary systems.
Post Production	In the film industry, this refers to activities that happen after the shooting of a film, such as visual effects and editing.
Preliminary Design Review (PDR)	This review within the NASA Flight Mission Lifecycle demonstrates that a Design meets objectives within acceptable cost, risk and schedule.
Producer	An individual responsible for financial aspects of the production of a film or other entertainment focused event or activity.
Product Design	The branch of Design that focuses on development of products focusing on the end-user.
Production	The term for a film, play, musical or other entertainment event when discussing the development.
Proposal	This is a term for a document of a plan provided to NASA HeadquArters by a field center for funding consideration.
Prototyping	An early model of a product created to test a concept.
Robotic Mission	This term within Aerospace refers to Flight Projects that have a robotic component.
Science Fiction Thinking	A Method of problem solving coined by Perception Studios. This Method utilizes Techniques from Feature Film to generate futuristic technology.
Science Mission Directorate	This NASA directorate focuses on answering fundamental questions about space through deploying satellites and developing technology for space.
Shape Language	A Design theory that uses shapes to communicate the general nature of an object.
Shillito Design School in Australia	A former Design Institution in Australia that represents Australia's link to the Bauhaus. https://cgscholar.com/bookstore/works/the-shillito-design-school
Sketching	A loose, quick Drawing that is intended to quickly get across an idea, but is not a finished work

Software Development	The process of developing the information behind how a computer will function.
Space Mission Lifecycle	This is one of the major processes used by NASA for development of space programs.
Story	A documented narrative that includes Characters and events.
Storyboarding	An organizational series of illustrations formatted in chronological order to depict the Story of a film, Animation or experiential piece.
Storytelling	The activity of describing a narrative.
Style	A distinctive way of Drawing or a way of dressing characterized by a particular time period or movement or place.
System Integration Review (SIR)	A review that determines if components and subsystems are ready for integration into a system. It also makes sure integration is on schedule and enough support personnel are available.
Systems Engineers	A branch of Engineering and management that focuses on development and management of complex systems over their lifecycles.
Technical Illustration	This discipline uses static and dynamic images and illustrations to explain the relationships between technical objects.
Technology Readiness Levels (TRLs)	A measurement system through which the maturity of a technology can be compared to other technologies of the same kind.
Testing	This term is the evaluation and analysis of a project.
Trade Space Analysis	Identifying alternative solutions to fulfill a new requirement of a project.
Transportation Design	A branch of Design focusing on the development of vehicles. Ergonomics may also be Designed. It emphasizes Aesthetics of emotion through Shape Language and Color Theory when Designing a vehicle
Typography	The theory and practice of letter and typeface Design.
User Experience (UX) Design	The Design of an entire product including branding, usability, Design and function.
User Interface (UI) Design	These Designers make interfaces for software, often focusing on stylization.
Video Game	A game produced through a computer to be played through electronic means.

Visualization	The representation of information as a Designed form.
Web Design	The production and maintenance of a website. This discipline can include skillsets such as Graphic Design and User Interface Design.
World-Building	The crafting of an imagined environment through which a technology is intended to be used.
Writer	An individual that produces books, scripts, stories and Articles as an occupation.
Zero Gravity	The state in space where there is no force of gravity.

Chapter 1 | Overview

1.1 Introduction

Within the Consumer Product and entertainment industries, effective use of Design Methods and Techniques utilized by the Design Discipline are known to be instrumental to project outcome. Footwear companies such as Adidas employ Designers who use Methods such as Design Thinking and Human Centered Design for development of their products. The Walt Disney Company and Universal Studios use similar processes in development of their theme parks, with the addition of utilizing Techniques such as Sketching, Prototyping and Storyboarding to develop concepts of rides for park guests. These Methods and Techniques are seen as essential for product implementation within these fields in problem solving and Idea Generation. [1, 2, 3]

This thesis defines Design professionals by the core skills of their educational training to more clearly define how they contribute to professional teams. Historically, dedicated Design colleges have been known to emphasize foundational courses in Color Theory, Shape Language, Drawing, and Modernism in their undergraduate studies. These foundational courses were largely inspired by the Bauhaus, a German Art school that found a Method of unifying Artistic practice, Craft and manufacturing at the beginning of the industrial revolution. The Bauhaus closed its doors in 1933, but it inspired the branching out of Design Disciplines, such as Industrial Design, Graphic Design, Concept Design, Fashion Design and Motion Design. [4, 5] Chapter 4 (Section 2) describes the differences in Sketching Technique between these disciplines.

The Aerospace Industry does not yet have a direct understanding of how to utilize the Methods and Techniques utilized by Designers. Chapter 5 shows evidence from interviews with Designers in Aerospace of an effort on the Designer's part in attempting to create understanding of their discipline among their Engineering peers. These experiences are reflective of interviews from Industrial Designers from Johnson Space Center's Habitability Design group. [6, 7]

This gap in knowledge is emphasized by insufficient academic research in understanding the impact and benefit of Design Methods and Techniques within Aerospace. This thesis attempts to bridge the gap between Aerospace and the professional Design practice in a few key areas: Methods, Techniques and documentation of processes. Researchers at the Jet Propulsion Laboratory, a NASA Field Center, have begun to shift the rigidly linear processes of the federally funded research center to include non-Engineering Disciplines. The work of Dr. Tibor Balint and Dr. Tony Freeman has shown a need to alter the organization's view of non-Engineering Disciplines within their flight project Design processes. [8] In a related field, Dr. Maria Yang, MIT D-Lab Faculty Academic Director, focuses on bridging the Engineering and Design Disciplines, particularly in early phases of the Product Design cycle. Dr. Yang's research includes the analysis of the Sketching skill and it's role in early stage Engineering Design. Her research also involves researching Methods for ideation and Prototyping as well as Design activity and Design outcome. [9, 10] While her work lies primarily in Product Design and its relation to Mechanical Engineering, it closely relates to Aerospace Engineering.

This work provides historical documentation to recognize how Design has contributed to the Aerospace Industry in the past. There is a documented history of individuals working in both Design for entertainment and Aerospace. Concept Designers in the past have worked on visual imagery for space mission concepts as well as Story Concept Designs for Feature Films, such as Star Wars (1977). Chapter 3 (Section 3) of this work showcases the beginnings of a timeline of Design Disciplines within NASA, a few of their first appearances within the organization, impact, and their relationships to other industries. Further data collection is needed to develop a complete timeline of the Design Discipline within NASA. Physical Artifacts such as NASA produced brochures, magazines, graphical assets, and films from the 1940's through the 1990's would imply the presence of a Designer within NASA and their specific Disciplines at those times in NASA's history.

Leaders in the Aerospace Industry have an opportunity to make effective use of specific Design Methods and Techniques that will likely bring value to the space mission Design process. Chapter 6 shares how the Methods and Techniques of Designers can be integrated into various phases of the flight project lifecycle. The Design Methods and Techniques described in Chapter 4 may help teams in achieving the goals of each phase as defined by milestones in the NASA Flight Mission Lifecycle. [11] Program Formulation phases may benefit from Methods that focus on ideation, while Implementation phases may benefit from Methods that focus on comparison of product outcomes. Evidence from interviews in Chapter 5 shows that Techniques such as Sketching, Storyboarding and Prototyping are used more frequently than any specific Method.

One way to increase understanding and utilization of Design Methods and Techniques is to develop clear mappings between the use of Design tools and needs of the Aerospace mission Design process. This thesis adds to existing literature by documenting specific Design Methods and Techniques and their benefits within Aerospace in the form of a catalogue inspired by the Netherland's Design Institute's approach to Design Method categorization. Designers at the Netherland's Design Institute catalogue Design Methods along with the costs, staff, time and expertise needed for each Method. [12] Understanding of Methods and Techniques is instrumental to correctly apply the skillsets of the Design Discipline. Consequences of not having a clear understanding of Design Methods and Techniques may be that Design professionals are not utilized at their full potential within Aerospace, and that these Methods and Techniques may be used incorrectly with no benefit gained.

This thesis opens with an overview of the Design practice within Aerospace. It is important to distinguish the differences between the Design and Art Disciplines to illuminate the systematic problem solving evident in the Design Discipline. Chapter 2 defines the practice of Design professionals and describes the components of a Design education built on foundational skills in Art. This discussion shows how current education practices evolved based on key historical influences, especially during the Industrial Revolution and World War II. This description is necessary to distinguish the Design Discipline from other systematic practices, such as Systems Engineers who have a science and Engineering foundational education. Chapter 3 shares the history of the NASA Artist in Residency program and its downscaling based on Congressional Legislation. This chapter discusses how the action by Congress relates to possible barriers for the Design Discipline within the Aerospace sector.

Despite these barriers the thesis shows that the Design Discipline does exist within NASA today and Chapter 3 contains a catalog compiled by the author of all publicly documented, dedicated Design Teams within NASA Field Centers to examine the disciplines involved and their current roles within the agency. Chapter 3 also showcases teams that were not catalogued as Design Teams and why their role does not fit the definitions for Design practice based on the discussion in Chapter 2. The same chapter provides historical examples of Designers within Aerospace.

Chapter 4 (Section 1) is a literature review of Exploratory Methods and Techniques used by Designers that will describe the Methods theorized by the author to support decision making during Space Mission Concept Development. These Methods include: Design Thinking, Human Centered Design, The Imagineering Process and Science Fiction Thinking. They were selected because they align with goals set by experts in Pre-Phase A mission Formulation, the earliest stages of space Mission Concept Development. Along with these Methods, Chapter 4 (Section 2) documents Techniques frequently used by Designers such as Sketching, Storyboarding and Prototyping. These and other Techniques are found to serve as the common set of components within many Design Methods. The author theorizes these Techniques to be supportive of the systems Engineering Discipline. Chapter 4 ends with the beginnings of a catalogue of Design

Methods and Techniques for use in Aerospace inspired by the Netherland's Design Institute's approach to Method categorization. [12] This catalogue outlines associated expertise, time, staff and costs for each Method. By cataloguing these Methods, a clearer understanding may be facilitated between Design and Aerospace Engineering.

Chapter 5 is the formal investigation of Exploratory Methods and Techniques based on personal interviews with employees within the Aerospace, Consumer Products and Entertainment Industries. These interviews shed light on whether certain Methods are used more than others and how often specific Techniques are currently used by the teams represented. This evidence describes opportunities and barriers to the use of Design Methods and Techniques within Aerospace. Chapter 5 shares the research Design and data collection Methods used in this thesis.

Finally, based on interviews, a literature review and historical evidence, Chapter 6 describes the NASA flight mission lifecycle through the lens of a Designer. The discussion describes each phase of the lifecycle, proposes Design Methods and Techniques that can be applied within each Phase and highlights where the Methods and Techniques may contribute to core functions and goals of each Phase. Chapter 6 provides evidence of the use of Design Methods and Techniques used in support of Aerospace and Proposals for how they may be utilized further.

The intent of this thesis is to provide insight into barriers for Designers working in Aerospace, and begin a Design library and taxonomy, where Exploratory Methods used by Designers can be categorized and utilized within Aerospace.

The author's research question is: What exploratory Design Methods and Techniques are currently utilized formally and informally within Aerospace and what barriers and opportunities exist to expanding these Methods and Techniques?

This question can be broken into two pieces. The first half, “What Exploratory Methods and Techniques are currently utilized formally and informally within Aerospace” and the second half, “What barriers and opportunities exist to expanding these Methods and Techniques.” Through interviews and historical evidence, the first half of the question is addressed. Chapter 4 illuminates the second half of the question through a literature review and research into Design Methods. Evidence towards answers is noted in each section.

Chapter 2 | Design and Art

Before beginning to discuss the possible benefits of the professional Design practice within Aerospace, this chapter distinguishes the differences between professional Design and the Art Discipline. There have been a variety of forms of Artistic tradition built in communities around the world. This diversity in tradition shows how Art plays a broadly defined role in societies at different times and places around the world. In the author’s experience, people from the Aerospace Industry often group the two disciplines together or confuse them with one another in the workplace. This chapter explains the definitions used for Design and Art and aims to reduce confusion between the two disciplines.

The American Institute of Graphic Arts (AIGA), the professional association for Design, describes Design as “…improving the visual appearance and function of messages and information.” Designers often work in business innovating marketing, Designing messages, branding and “services that express the character of a company and define its relationships with consumers.” [4] Various disciplines of Design are highly specialized and work in technology and product development. Design Disciplines include, but are not limited to: Advertising, Information Design, Illustration Design, Motion Graphics Design and Industrial Design. While these disciplines are highly specialized, all Design Disciplines use Drawing, Typography, graphic elements, and photographs to solve problems. Looking further than Aesthetics, Designers support technology and its role in our future. [4] It can be said that the Design Discipline is constrained to focus the problem it is trying to solve rather than creating for the sake of expression.

Whereas all Design Disciplines focus on solving problems, Artistic Disciplines can be vastly different in their focus. Historical evidence shows there is no clear demarcation of the lines of separation between Art and non-Art and the definition of Art is often disputed. [13] In perhaps one of the most embraced theories of Art in the United States, Plato's Republic states that Art is an "Imitation of Reality". He describes that Art imitates the objects and events of ordinary life. Pragmatism Aesthetics thus, describes Art as follows, "Art heightens life's meaning by putting experience or action into a formal, focusing frame that intensifies that experience or action… transfigures it, making it special even if its material was initially ordinary." [14]

While Plato's theories focus mostly on literature, Painting and Sculpture, in China, Versification was a dominant Art form. Versification is the making of verses through a metrical structure. Artistic theory in China was based on personal experiences and literary criticisms. [15] In Pre-colonial Mexico, 3,000 years of Artwork was created by the indigenous population and valued religion and animal life. Tarascan Artwork of the region was comprised of circular and rectangular shapes with bright pops of color. [16] Artists in Pakistan also valued religion, often referencing Islamic ideology. When Artwork is in the form of Calligraphy, shapes, lines and forms are drawn to imply movement and spirituality. [17] Pre-colonial Indigenous Inuit Artwork in the Arctic depicted animals and Inuit traditional beliefs. Sculptures were hand carved from walrus ivory, stone and caribou antlers. This practice continues today. [18] Author Janos László describes the disciplines of Painting and Sculpture as "two wholly different and opposed phenomena, both of which are called Art, even though one is a negation of the other." [13]

Artwork historically plays a role in the daily lives of individuals. Through Artwork, spirituality can be expressed as well as individual insights on the world. Historical

Artwork provides insights into daily life of the period that are abundant in information about individual experiences. Artwork changes through time and documents transitions in political, economic and social phases of a time period.

Art is defined by the Oxford dictionary as "the expression or application of human creative skill and Imagination, typically in a visual form such as Painting or Sculpture, producing works to be appreciated primarily for their beauty or emotional power." In an exploratory interview with an MIT Media Lab Artist and former Artist in Residence at CERN, they describe Art and Design as having fundamental differences. The Artist sees Art as "posing a question" and Design as "solving a problem." In some instances, an individual can be both an Artist and a Designer, which is explored in Chapter 2 (Section 2). This thesis will use the Oxford definition of Art primarily for appreciation of beauty and emotion, which is fundamentally distinct from Design's focus on systematic problem solving.

2.1 Design in Practice

In recent years, the Consumer Product Industry has faced tension in their Innovation practices. With the advent of Computer Aided Design software such as Autodesk and Solidworks, product development time has reduced and customers now have more options to choose from. [19, 20, 21] Professionals in disciplines such as Industrial Design frequently work with Engineering professionals to improve the ergonomics and function of a product. Design is recognized as a catalyst for product change in the Consumer Products Industry for its commitment to systematic Design Methods. [19] The Design process can take various forms; it can focus on "Intuitive Creativity" or be "Science Based", focusing on calculated decision making. [19] The following is a brief review of the Industrial Design practice, because of its overlap with other systematic Design Disciplines that span other industries including, but not limited to: Product Design, UX Design, UI Design and Concept Design.

The birth of Industrial Design can be linked to the 18th century's Industrial Revolution, when consumer consumption habits began to change in accordance with evolving manufacturing efforts. Industrial Engineer Jacques-Eugene Armengaud published his book, "The Practical Draughtsman's Book of Industrial Design," (1851) in an effort to address the changing landscape. The subtitle of the book states that it provides a "complete course of mechanical, Engineering, and architectural Drawing." His predictions Alluded to Industrial Design becoming a universal language through standardization, functionality and efficiency. [22]

In one of the earliest writings on Industrial Design featured in "*The Art Union, a monthly journal of the Fine Arts*" 1839, the state of the Design School of Fine Art in the Netherlands is evaluated. It states that students are to enter their program as if intended to be Artists "in the higher sense of the word" and are not expected to make a decision on whether to pursue Design or Art until "completion of all Drawing and Painting courses". [23] In similar efforts to address the changing landscape of the 18th century, a few universities were formed who's influence still affect the Design practice today.

The Bauhaus, possibly the most influential Design School of the 20th century, became regarded internationally for its implementation of the Design practice. The Bauhaus was a German school that combined beauty with function and unified the principles of mass production with the "individual Artistic vision" of the Arts and Crafts movement. While it had a short run from 1919 to 1933, pressured to close its doors by the Nazi regime, the principles of Design developed by the Bauhaus are deeply influential to modern developments in Design fields such as Architecture, Graphic Design, Fashion Design, Product Design and Industrial Design. [5] Subsequent schools adopted their framework and philosophy, such as Art Center College of Design, Institute of Design (Chicago) and Harvard Graduate School of Design, where the founder of Bauhaus later became professor. [24]

The Bauhaus curriculum included basic principles of Design, Color Theory, and experimenting with materials and processes. Their foundational courses amplified their objective of unifying Art, Technology and Craft and reflected a functional Method of integrating theory and application. [5] This approach to Design Education is now common at Design institutions globally. After the Bauhaus was disbanded by the Nazi party, Designers involved took their Design work outside of Germany; this work can be seen reflected in Design institutions around the world. Art Center College of Design is an example that currently applies philosophies and curriculum that were made well known by the work of the Bauhaus. [24]

Outside of the United States, educational institutions influenced by the Bauhaus include: Melbourne School of Design, [25] The Shillito Design School in Australia, [26] Bezalel Academy of Arts and Design Jerusalem, [27] and the China Academy of Art. [28] Additionally, Tel Aviv's cultural heritage site "White City," a series of building Designs reflective of the Bauhaus in the 20th century, is supported by the Bauhaus Center Tel Aviv. [29]

Other institutions rose around the same time as the Bauhaus, often opposing their curriculum. One such institution was the experimental Art School, Kala Bhavana in India. Founded by Nobel Laureate Rabindranath Tagore in 1919, the School dismissed the philosophies underlying colonial Art. It played a large role in shaping modern Painting in India. This school paved a contrasting path from the Bauhaus in its rejection of Western minimal styled architecture and had a preference for the ornate. [30]

Design Institutions today have evolved to include other courses for Industrial Design and other disciplines, such as Visual Development, 3D Modeling and Industrial Design Research. [10] Industrial Designers use varying Design Methodologies and Techniques to accomplish their work. Often, programs focus on Design Thinking as a Methodology and emphasize sophisticated Prototyping, Drawing and Sketching as Techniques along with use of various traditional and digital mediums such as markers, pen, ink, and computer software. [10]

Industrial Design Education often overlaps with other Design Disciplines that follow similar, if not the same foundational courses as Industrial Design. Design Disciplines branch out to specialize in specific fields, such as Apparel Design and Entertainment Design as discussed below.

Onen example from the Apparel Design Industry is Adidas. Consumer focused organizations such as Adidas frequently hire Industrial Designers into leadership positions, often having their own in-house Design Teams. Designers at Adidas Design footwear as well as explore materials and function. Their work begins with Sketching, continuing into finished Drawings, exploring fabrics, creating Prototypes, Technical Illustrations and building the final Prototype. [1]

The Entertainment Industry's Concept Designers also develop products; however, their Design process emphasizes advancing a Story for Feature Film or telling a story for visitors to a theme park. Concept Designers frequently Design props, vehicles and environments for live action Feature Film, Animation and Video Game production through use of Sketching, Drawing, and computer software such as Adobe Photoshop, Solidworks and CAD modeling software. [20, 21, 31] Concept Designers take into account historical context, materials and patterning while Designing. Prior to digital technology, Designers in the Entertainment Industry used traditional media such as watercolor, acrylic and oil paints. Designers currently use Methods such as Shape Language and Color Theory historically reminiscent of the Bauhaus are used to play at the subconscious. Through these Methods, a Designer can influence the way a viewer interprets objects and characters. For example, a vehicle can be Designed to appear dangerous to the viewer. From the author's experience in Concept Design, an example can be seen in the vehicle of a villainous character in a film. Sharp angles and dark purple hues may imply “villain,” even when not explicitly stated in the film. The outcome of the Drawing is still a vehicle, but it is Designed for Audience consumption.

Leadership within Entertainment Firms often promote Concept Designers to different roles and have varying titles, such an Art Director or Concept Artist. The term Art here does not reflect a lack of systematic Design processes involved in development of final products and assets. While the foundational education of Concept Designers may be similar to that of Industrial Designers, the final product may be slightly exaggerated to advance a Story’s emotion and plot. Figure 1 shows an example of a backpack drawn in two different styles, one utilized by Concept Designers and one by Industrial Designers. The Concept Designer draws the Entertainment style backpack as if it has been used by a Character. The Audience can infer that the backpack is possibly handmade and that the character uses it to carry straw and fabric. This information implies that this Character may be a merchant. The Industrial style backpack is drawn in a style intended for manufacturing. Industrial Designers use this style of drawing in the Consumer Product Industry, often accompanied by measurement and material annotations.

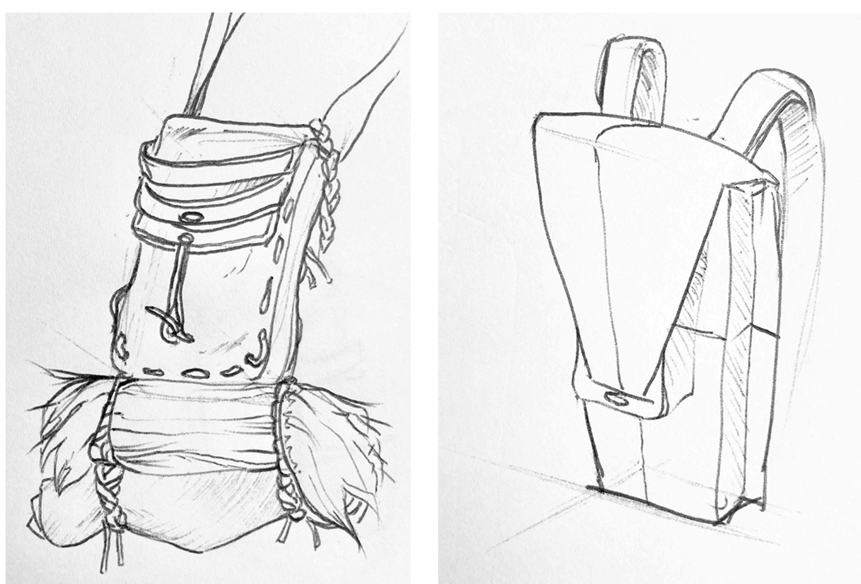


Fig 1. Depicts an Entertainment style concept sketch of a backpack, juxtaposed with an Industrial Design style Sketch of a backpack. The difference is the intended outcome, but the same Technique (Sketching) is used. Image credit: Lizbeth B. De La Torre

The Walt Disney Company, known for its support of Design since its inception, involves Concept Designers in its Attraction Design. Eddie Sotto, in "The Imagineering Story" a documentary on the Design and implementation of Disneyland, describes the role of Concept Designers at the beginning of the process: "Walt started with Architects, he had consultants in the amusement park business, different ones, but all the king's horses and all the king's men couldn't give him the answers he wanted. He brings in Art Directors because Architects were giving him Architecture. The Art Directors could give him the scale, the feeling, could replicate anything, they're can-do guys." Walt Disney brought on Designers from his Animation studio, who were accustomed to "communicating visually" to develop Concept Design work for the park. [32] Walt Disney recognized the differences between the Sketching Techniques used by Concept Designers and Architects. These differences are described in Chapter 4 (Section 2).

John Hench, one of the first Disney Imagineers has stated on this topic, "I don't think it could have been built without people that have had some sort of motion picture experience, we relied so much on all the Techniques, Idea and Story very much as you do in motion pictures." [32]

Universal Studios, in its theme park development, has also been led by Designers. Universal Studios was designed to provide a backstage view of a working Hollywood studio. Universal's primary focus was to allow park guests to "ride the movies." And its creative team, Universal Creative, is composed of Artists, Engineers, Designers, Producers, and Writers similar to Disney Imagineering. This team brings their theme parks to life. The Entertainment Industry uses similar project development terminology, such as using the word "Attraction" to define a ride or guest experience. [3]

2.2 When Design and Art Overlap

In some instances, Designers can also be Artists, or vice versa. They may fulfill dual roles within institutions. As stated earlier in this work, in the intent and process lies the final product. The following few examples depict Designers as Artists with a focus on Computational Art and Installation Art. These two Art forms were selected to represent the digital space and physical space and are representational of the Design Discipline applied to the Art practice. These examples show evidence of individuals fulfilling dual roles as Designers and Artists.

Computational Art is Art that uses computer technology as the main medium. One of the most influential Computational Artists and Designers of the 20th century, Muriel Cooper, created significant Illustrations and gallery Artwork based on her Design process in both print and digital media that still influences Design today. She adapted her expertise of the print medium to software and foresaw its production process as interfaces and experiences for the digital screen. [33] During her time as the MIT Press, she instilled a Bauhaus influence into their publications as their Art Director; she later went on to co-found the MIT Media Lab. She did not learn to code software, however, she foresaw the Design opportunities of the medium and experimented with concepts in presenting complicated information. [33] [34]

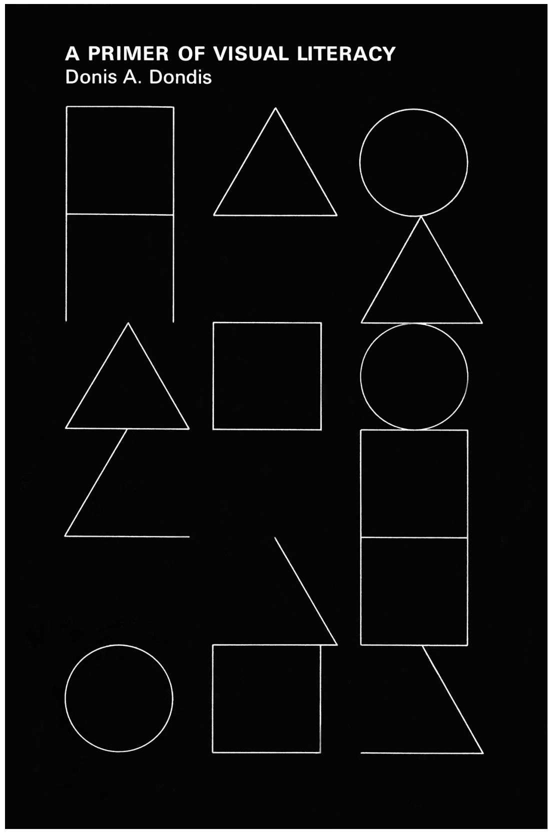


Fig. 2 Muriel Cooper, Artwork for Donis A. Dondis, A Primer of Visual Literacy, 1973. MIT Press Design Department, Cambridge

Additionally, in the field of Computational Art and Design, a notable Artist is John Whitney Sr. As an animator and inventor, his approach to developing mechanical Animation led him to becoming an Artist in Residence at IBM. In his younger years during World War II, Whitney worked at a Lockheed facility on high speed missile Photograpy. He realized that the targeting elements in weapons like missiles and bombs had within them detailed numerical equivalents. He eventually acquired these targeting mechanisms and used a converted World War II M-5 anti-aircraft gun director to create his own Drawing machine. He was able to control cameras through the use of computers. Leaders in Animation often refer to him as one of the grandfathers of Computer Animation. [35]

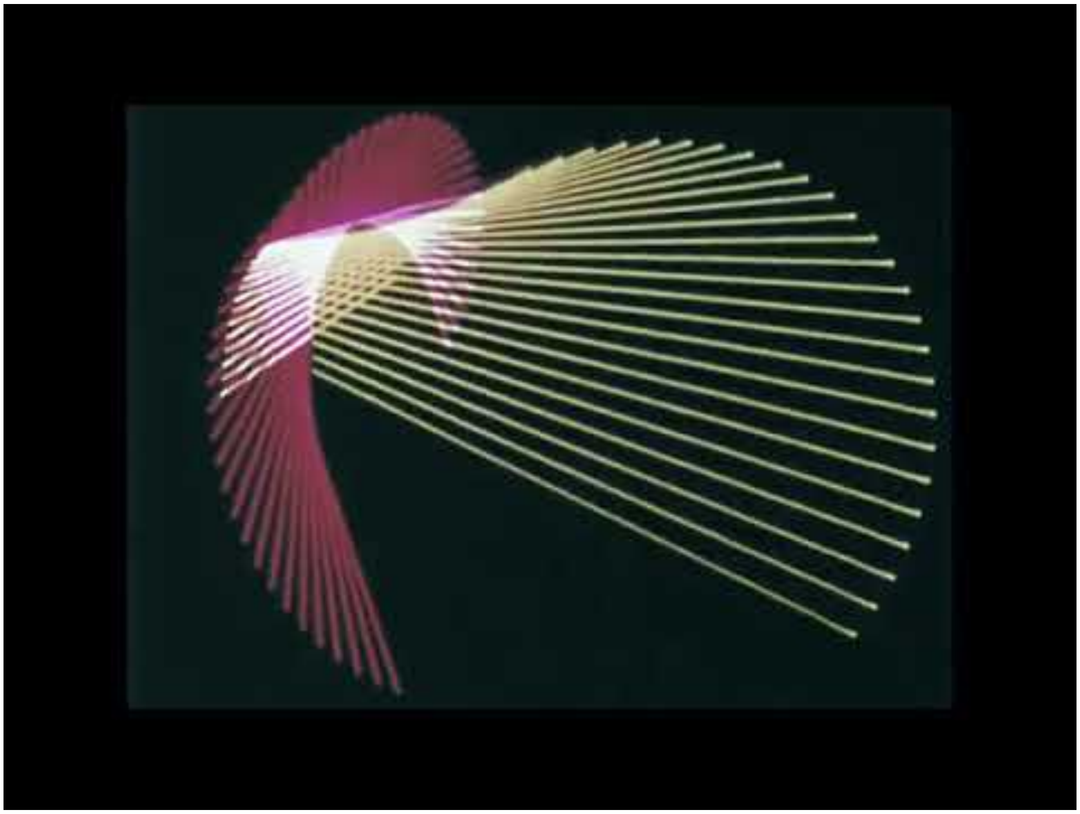


Fig. 3 John Whitney Sr., Experiments in Motion Graphics, 1968

Installation Artwork contains a variety of media, including sound, video performance and virtual reality. This genre is meant to transform spaces and can be temporary or permanent. [36] NASA's Jet Propulsion Laboratory in Pasadena, California houses a small team called, "The Studio," a team of "Designers, Artists, Makers, Strategists, and Thinkers". They are passionate about helping scientists and Engineers imagine the future, and giving people a sense of awe about the universe. "Imagining the future" for The Studio means using Design Methods and Techniques such as Design Thinking, Human Centered Design, Sketching, illustration, Prototyping and Storyboarding to develop ideas ranging from Mission Concepts to public Outreach experiences. Their Orbit Pavilion, on display at the Huntington Memorial Gardens, is an Art Installation that takes NASA data from 19 Earth science satellites and the International Space Station to connect humans to space through real time sound playback. [37]

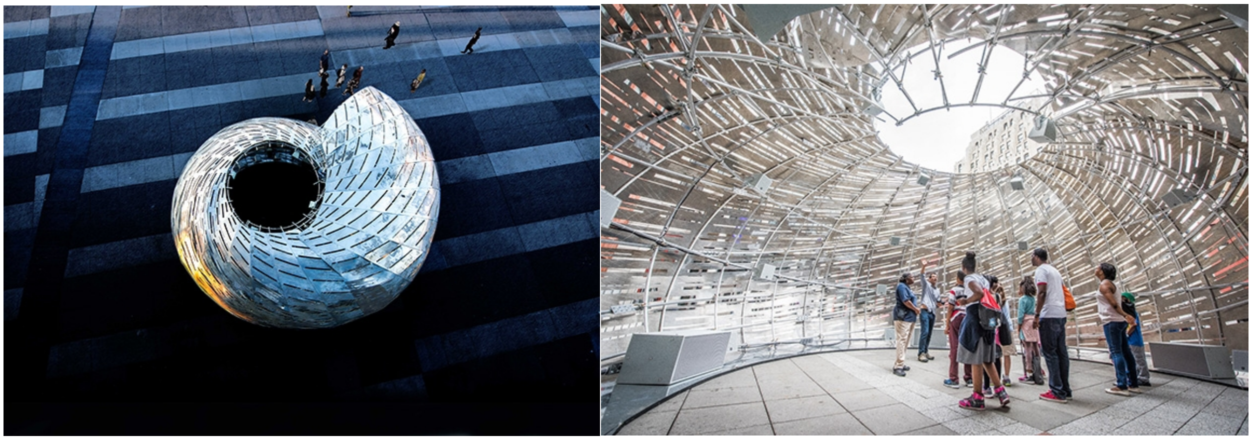


Fig. 4 Orbit Pavillion, NASA/JPL-Caltech

The work of Tomás Saraceno focuses on Art, life sciences and social sciences. In the past he has created work relating to the environment. His 2007 installation, Aero Solar was meant to inspire “an ethical collaboration with the atmosphere.” It was a large balloon Sculpture that imagined how humans might float into space without the use of rockets. He has since started an international campaign titled, “Space without Rockets.” This project consisted of a multi-disciplinary team and inspired global collaboration as an Art piece. Tomás’s work is largely science based and utilizes phenomena such as thermodynamics of the atmosphere. Constructivism is a key influence in Tomas’ work; this Artistic philosophy rejects aesthetic stylization, while instead leveraging the industrial assembly of materials.[38] [39]

This Chapter shows that Art may utilize the stylization and Techniques of Design because of the freedom within the Art practice to utilize a variety of media and Techniques to create for beauty and emotion. As stated earlier in this chapter, there is no clear demarcation to distinguish between Art and non-Art, however it can be seen from this chapter that it is possible for a Designer to be an AArtist, or an Artist to be a Designer at the same time.

2.3 Artists in Residency

Because the terminology to distinguish between Design and Art Disciplines is sometimes misinterpreted, this section provides background on NASA's Artist in Residency program, the reasons for its considerable downscaling and the possible barriers it has created for both Artists and Designers in their work in the Aerospace Industry. Designers are often associated with Artists because they share common aspects in their education, Techniques and skillsets.

NASA's Art Program was established in 1962, shortly following NASA's founding in 1958. Administrator James Webb, impressed by his work, commissioned Artist Bruce Stevenson for portraits of all NASA astronauts. The program was established to celebrate "past and future events." Historical documents provided by NASA note that James Webb appreciated and saw the importance of showcasing the emotion behind space exploration. [40] The early NASA Art Program created opportunities for Artists to witness historical events, providing them with experiences to produce and share their work with the public. NASA also provided a modest stipend to the Artists. In the following decade Artists such as Annie Leibowitz, Norman Rockwell and Andy Warhol participated in the NASA Art program. [40]

While its stiped increased over the years, the NASA Art Program was largely downscaled in 2005, following a Congressional Amendment to the Science, State, Justice and Commerce Annual Appropriations Bill. Indiana Republican Representative Chris Chocola cited Artist Laurie Anderson's stipend of $20,000 to create and perform a theatrical piece about NASA as wasteful spending. The Appropriations Bill was amended "*to prohibit federal funds from being used to employ an 'Artist in Residence' at NASA.*

The following page is an excerpt from the Congressional Record on June 15, 2005 regarding the Amendment:

Science, State, Justice and Commerce Annual Appropriations Bill, 2006

[Excerpt]

Amendment No. 1 Offered by Mr. Chocola

Mr. CHOCOLA. Mr. Chairman, I offer an amendment.

The CHAIRMAN. The Clerk will designate the amendment.

The text of the amendment is as follows:

> Amendment No. 1 offered by Mr. Chocola:
>
> Page 108, after line 7, insert the following:
>
> TITLE VIII--ADDITIONAL GENERAL PROVISIONS
>
> Sec. 801. None of the funds made available by this Act may be used by the National Aeronautics and Space Administration to employ any individual under the title ``artist in residence''.

The CHAIRMAN. Pursuant to the order of the House of June 14, the gentleman from Indiana (Mr. Chocola) and a Member opposed each will control 5 minutes.

The Chair recognizes the gentleman from Indiana (Mr. Chocola).

Mr. CHOCOLA. Mr. Chairman, I yield myself such time as I may consume.

Mr. Chairman, I thank the gentleman from Virginia (Mr. Wolf) for his good work on this bill. I also appreciate the opportunity to offer this amendment.

This amendment is really about prioritizing spending and fiscal responsibility. Over the last 2 years, NASA has spent $20,000 for an artist-in-residence program. My amendment is designed to prevent or limit that practice in the future.

Mr. Chairman, nowhere in NASA's mission does it say anything about advancing fine arts or hiring a performance artist. In fact, Laurie Anderson, the person that was chosen to perform the role of a performance artist, when she was called to be offered the job, she said, Sure, what do I do?

And the response she got from NASA was, Well, we do not know; we have never done this before.

One of the first things that I did in 2003 after I showed up as a new Member of Congress is I attended a memorial service for the Columbia astronauts. Certainly, spending money by NASA on a performance artist and a artist-in-residence program does nothing to make sure that the shuttle program gets back into space and prevents such tragedies in the future.

Now $20,000 may not seem like much in the Halls of Congress; but to the average American family, it is a significant amount of money. I wish I could say that NASA is boldly wasting taxpayer money where no agency has wasted it before, but I am afraid that the artist-in-residence program is just a symptom of a bigger problem.

Recently, the Heritage Foundation identified $386 billion of waste, fraud, and abuse in government spending. Every American business and every American family must make hard decisions to stand by their budget and eliminate wasteful funding, and the Federal Government should be no different and NASA should not be spending taxpayer dollars on a performance artist. I encourage all of my colleagues to support this amendment.

```
  Mr. WOLF. Mr. Chairman, will the gentleman yield?
  Mr. CHOCOLA. I yield to the gentleman from Virginia.
  Mr. WOLF. Mr. Chairman, I think this is a good amendment and I accept
  it.
  Mr. CHOCOLA. Mr. Chairman, I reserve the balance of my time.
  Mr. MOLLOHAN. Mr. Chairman, I move to strike the last word.
  Mr. Chairman, I rise not in opposition, I am going to agree to the
amendment, but I would like to have some comment before I do.
  Mr. Chairman, I think this is a regrettable amendment for a number of
reasons.
  First of all, it involves an awfully little bit of money. Secondly, I
think it sends a really bad signal. Indeed, one of NASA's missions is
to inspire; and it has had an arts program, a very small arts program
since 1962. Such luminaries as Norman Rockwell have participated in it
over the years.
  It is in furtherance of part of NASA's mission. NASA's mission is to
inspire, to educate. Indeed, in the education theme of NASA's FY 2006
budget, it states: ``To develop the next generation of explorers, NASA
must do its part to inspire and motivate students to pursue careers in
science and technology and engineering and in mathematics.''

                              {time}  1500

  A part of it is connectivity. One of the ways NASA has done that, if
anyone has visited its facilities, is through beautiful murals and
other art initiatives. This particular initiative that the gentleman is
speaking to is the appointment of Laurie Anderson as an

[[Page H4531]]

artist-in-residence, which is another phase, if you will, in NASA's
arts program. It is a worthy program. It has developed over those years
since 1962 an awful lot of memorable artworks. There is no reason to
believe that this initiative, which is so modest in nature, would do
anything but further enhance the arts program at NASA. Again, it is so
small that it is just minuscule. I am afraid the amendment really
represents more art bashing than it does good fiscal policy.
```

There were arguments against this Amendment, particularly for the modest amount of spending and NASA's goal of inspiring and educating the public. This amendment passed and NASA can no longer allocate funds for an Artist in Residence.

The Artist in Residence program is only one part of NASA's Art Program. The Program still exists today led by Bert Ulrich. His office curates and preserves the work commissioned from Artists for NASA in the past. Bert Ulrich's office and the NASA History Office also coordinates with filmmakers and Artists if they need information about

NASA's work or history for their creative endeavors. The agency no longer commissions Artwork with financial support, however NASA does offer access to Artists for tours, events, facilities, interviews and data to support their Artwork. [40]

Concerning barriers that may be caused by this Amendment, a NASA Article describing the Artist in Residency program also depicts the work of The Studio, which describes them as Artists, leaving out the terminology of Design. [41]

Other science institutions have Artist in Residence programs in place today. The European Organization for Nuclear Research (CERN) houses an Arts program that connects Artists with particle physicists. They support Artistic Innovations in research environments by inviting Artists to work alongside scientists and Engineers. In an exploratory interview for this thesis, an MIT Media Lab graduate student who recently spent time in CERN's residency program stated that CERN inspired curiosity and intuition in different ways. She mentioned that some residencies expect a finished product at the end and some can be more research based and do not require a finished piece. [42]

It can be seen that the Design and Art Disciplines are distinct in their approaches: Art meaning to pose a question and Design intending to solve a problem. The Design Discipline's roots in Artistic Technique education perhaps leads to misinterpretations of both disciplines. A professional Designer is defined in this thesis as an individual who has gone to a Design school and studied foundational courses in Design including: Color Theory, Shape Language, Modernism, Drawing and Design Methodology.

Chapter 6 shows that teams working on space mission architecting often need to both "pose a question" and "solve a problem" when opening a trade space and narrowing down to a solution. Space Mission Architecting is the process of creating a plan and specifications for the implementation a spacecraft mission.

Chapter 3 | Designers in Aerospace

The following chapter provides a catalog of where Design Teams exists today within NASA and teams that are not considered dedicated Design Teams for the scope of this thesis. This chapter also provides historical examples of the professional Design practice within NASA to begin to document the emergence of this discipline, however further research is needed and will be conducted in the future for a more complete historical view.

Design teams within NASA are comprised of the Design Disciplines mentioned in Chapter 2, such as Illustration Designers, Graphic Designers and Industrial Designers. It is intended that the term “Design Team” in this chapter is a team comprised of mainly individuals who have foundational education in Design as described in Chapter 2. The author could find no evidence of data that provides the exact number of dedicated Design Disciplines within NASA, however a summary of team objectives may imply specific disciplines involved.

There are teams within NASA that are not considered dedicated Design Teams for the scope of this thesis, such as Mission Design Teams that are comprised of Engineering Disciplines. They are further described in Chapter 3 (Section 1).

3.1 Design Teams within NASA

Aerospace agencies have within the last 10 years begun establishing their own in-house Design Teams. One example is Johnson Space Center’s Habitability Design Center, which is described by team members as NASA’s “Human Centered Design studio.” This team of Industrial Designers support the development of Human Habitation. On their work, they have stated that “Things have changed so much since we started, people here don't really understand what Industrial Design is or how it fits into the bigger picture. But once they work with us and see the services we provide—visualizing information, realizing concepts—they see the value of what we do." [7] Additionally, their interview with journalists at Core77 states, "there isn't a place for industrial Designers at NASA. Here the Engineers are considered the Designers, and the team has only been able to exist under the guise of Human Factors, a quantifiable soft science that is acknowledged as necessary." [7] NASA recognizes Human Factors as an Engineering Specialty within NASA that imposes requirements on systems, however Engineering Specialties are usually not integral to solving the problem of Design itself. This quote infers that the speaker experiences a lack of appreciation for Design among Engineering colleagues. Anecdotal evidence from interviews in Chapter 5 suggest this attitude may be true throughout the Aerospace Industry.

There are pockets of Designers within NASA both formal and informal. The chart below depicts the author's findings of NASA Centers and the publicly available information on formal Design Teams within them. Information on NASA was collected because of the quantity of publicly available data on Design Teams. For each NASA Field Center, terms such as "Design Teams", "Graphic Design", "Industrial Design", "Illustration", "UX/UI Design" were searched for through an online search engine and academic literature database. This analysis defines Design Teams here as those in which a majority of the members are Designers, with a foundational education in the Design practice as seen in Chapter 2. Leaders and supervisors of these teams may be Engineers. This chart does not distinguish between technical Design specialties within teams; the chart lists teams because of their use of Design Methods and Techniques, which are a staple of a Design Education. This list may be inconclusive because teams may not publish publicly available information.

Designated Design Teams within NASA	
Ames Research Center	Human Centered Systems Lab, Graphic Design Team
Jet Propulsion Laboratory	The Studio, Ops Lab, Visualization Technology Applications and Development Group, Human Centered Design Group, Graphic Design Team
Langley Research Center	Graphic Design Team
Goddard Space Flight Center	The Scientific Visualization Studio, Graphic Design Team
Johnson Space Center	Habitability Design Team, Graphic Design Team
Marshall Space Flight Center	Exhibits and Artifacts Team
Armstrong Flight Research Center	Web Team, Photo and Graphic Design Department
Kennedy Space Flight Center	Graphic Design Team
John C. Stennis Space Center	Graphic Design Team
Glenn Research Center	Graphics and Visualization Lab

The discussion below describes the Design Teams within different NASA Field Centers based on publicly available information from web pages, job descriptions, web Articles and academic literature.

Ames Research Center

Ames Research Center has expertise in Information Technology, Aerospace and Aeronautics Engineering and Research. They also conduct research in Space, Earth, Lunar and Biological Sciences. Expertise within Ames includes topics such as the following: The design of systems to enable spacecraft to safely enter other planets; designing advanced computing & IT systems; studying future Methods to help planes, drones and spacecraft operate safely in the atmosphere; asking how to identify whether life exists on other planets (a field called astrobiology and life sciences); and work on space missions in the fields of Space and Earth Science. Ames Research Center is supported by two Design Teams: the “Human Centered Systems Lab” and a Graphic Design Team. Their Human Centered Systems Lab researches human and system interactions, often with the aid of Human Centered Designers to implement and analyze software products. Lab lead Quang Dao’s published research in Human-Machine Interaction is focused on interactions between aircraft and pilots. [43] Not much is publicly known about the Ames “Graphic Design Team”, however it is known that most NASA centers have a dedicated Graphic Design Team that provides graphical asset development and visual language. They may be embedded within the Communications Team as is done with other NASA Field Centers.

Jet Propulsion Laboratory

The Jet Propulsion Laboratory focuses on robotic missions for Earth Science and Space. JPL sends robotic missions to study asteroids, planets, comets and Earth’s moon. They have perhaps the highest quantity of dedicated Design Teams of all centers. “The Studio” describes themselves as a team of “Designers, Thinkers and Makers” that develop ways of Storytelling and translating science through visuals as well as use Design Thinking Methods and Techniques to help Engineers “think through their thinking.” They apply these Techniques to help Mission Formulation Teams and Space Mission Teams meet their goals. [44] In a similar vein, the “Visualization Technology Applications and Development Group” creates interactive apps and visuals to communicate to the public and internally. An example of an interactive visual is their “Eyes on the Solar System,” that provides the user access to solar system data in an interactive map. [45] Their Graphic Design Team develops internal and external communications graphical assets as well as internal communications materials. JPL’s Human Centered Design Team, part of the Operations Lab (Ops Lab) utilizes Methods from Human Centered Design to develop natural user interfaces to support NASA's robotic space missions. [8]

Langley Research Center

Langley Research Center works to make improvements to aviation, expand knowledge of Earth's atmosphere and develop technology for space. Langley houses a Graphic Design Team, similar to other centers. While not much is publicly known about this team, other Graphic Design Teams appear to support internal communications through development of graphical assets for internal and external use.

Goddard Space Flight Center

Goddard Space Flight Center builds spacecraft, sensitive Instruments and technology such as telescopes to study the universe, solar system and our sun and Earth. They also manage communications between mission control and the International Space Station. Apart from a Graphic Design Team, Goddard houses a Scientific Visualization Studio that creates Visualizations and multimedia in order to foster a greater understanding of Earth and space science research activities. These teams further NASA's goals of enhancing public knowledge of space. A research paper sharing the hardware used for these Visualizations describes the use of Visualization focused super computers applied to science data sets. [46] [47]

Johnson Space Center

This Field Center is the base for astronaut training and mission control. It currently leads Operations for the International Space Station, development of NASA's Gateway project and the Orion Spacecraft while also advancing technology, Engineering and medicine to support space exploration. While this center houses a Graphic Design Team, Johnson also employs a Habitability Design Team. [7] It is composed of Industrial Designers and Human Centered Designers that focus on the human experience when developing vehicles and environments for space that humans will interact with. [48] A research paper by the former Associate Chief of Human Systems Integration at Johnson Space Center supports the inclusion of the Human Centered Design Method in the Flight Mission Life cycle. [48] Chapter 6 (Section 2) further discusses Human Centered Design in the Flight Mission Lifecycle. Additionally, Johnson's Integrated Graphics Operations and Analysis Laboratory develops Engineering Visualizations for Johnson as well as other centers. [49]

Marshall Space Flight Center

Marshall Space Flight Center focuses on developing propulsion systems and hardware, Launch Vehicles and related technology. This NASA Field Center houses an Exhibit and Artifacts Team that creates realistic models of spacecraft internally and for other centers. They manage various exhibit Artifacts along with developing Visualizations. Their visitor center, the U.S. Space and Rocket Center, houses space Artifacts from the beginning of the space era. They also host traveling exhibits from around the world. Their exhibits result in thousands of guests per year. [50]

Armstrong Flight Research Center

Armstrong Flight Research Center is centered on Aeronautical Research. It operates some of the most advanced aircraft in the world. It also houses several of NASA's Science Directorate aircraft including SOFIA (Stratospheric Observatory For Infrared Astronomy). This NASA Field Center has a dedicated Web Development Team, and a Photo and Graphic Design department. Their Web Development Team Designs for the web, while their Photo and Graphic Design departments create visual assets for internal and external use. [51]

Kennedy Space Center

Kennedy Space Center is the primary launch center for human space flight. Launch Operations for Skylab, Apollo and the Space shuttle programs were conducted at this NASA Field Center. This center also facilitates launch Operations for launches of robotic spacecraft and commercial Crewed Missions, as well as, conducting food and in-situ resource utilization research. This center has a Graphic Design Team, however, nothing else is publicly known about other dedicated Design Teams.

John C. Stennis Space Center

This NASA Field Center is a rocket testing facility; it is NASA's largest rocket engine testing facility. Over 30 private and public companies and government agencies use this center as a rocket testing facility. It is known that a Graphic Design Team exists through listings on a professional networking website. The author could not find public information about Disciplines of the team or work involved.

Glenn Research Center

Glenn Research Center develops science and technology for space exploration. Their facilities include Plum Brook Field Station that serves as a large-scale testing facility, an Icing Tunnel that simulates atmospheric icing conditions and a Zero Gravity Research Facility comprised of a vertical vacuum chamber for microgravity experiments. These facilities are all used to test space craft and science Instruments under the environmental conditions of space. This center houses a Graphic Design Team and a Visualization Lab. Their Visualization Lab applies Visualization technology to create solutions for the science community. Designers create Visualizations from data and models for the projects of scientists and Engineers. [52]

The Chart below briefly describes the Design Disciplines within NASA, based on the author's research into dedicated Design Teams.

Design Disciplines within NASA	
Technical Illustration	This discipline uses static and dynamic images and illustrations to explain the relationships between technical objects.

Concept Design	The development of an initial idea, often illustrated for visual aid and communication with clients.
Model Making	The creation of an object, often with a high level of detail at varying scales of size. Used as prototypes or for communication purposes.
Web Design	The production and maintenance of a website. This discipline can include skillsets such as Graphic Design and User Interface Design.
Graphic Design	Visual communication through Photograpy, Typography, illustration for communications purposes.
UI/User Interface Design	These Designers make interfaces for software, often focusing on stylization.
UX/User Experience Design	The Design of an entire product including branding, usability, Design and function.
Illustration Design	This discipline creates Illustrations for a specific purpose. Within NASA, this is the translation of scientific data.
Animation	This discipline creates moving images that communicate an action or data set.

The Chart below describes NASA teams that may be perceived as dedicated Design Teams, but are not included in the scope of this category based on the definitions within this thesis because of the Engineering disciplines involved. While the word Design may be in the title, they are not dedicated Design Teams because they are not composed primarily of individuals from a Design Discipline as described in Chapter 2. The word "Design" within Aerospace has a procedural meaning, often implying the development of a plan for the construction of a technology or for the implementation of a project. An example might be a space mission project, such as the development of the Mars 2020 Rover.

Some NASA Field Centers follow a Matrix structure for their operation. Matrix organizations can be identified by most individuals having two supervisors; one that can organize and supervise work to meet objectives, and another that gives the organization proper capabilities to accomplish work. In other cases there may be multiple project specific managers. [53] Design Teams, often referred to as "Project Design Teams" consist of Engineers and other disciplines, sometimes including Designers, who are brought together to work collaboratively on what can be referred to as an Architecture for a space mission project. [54] Matrix models allow for employees to have a home organization that nurtures their individual skillset, but can work with others on teams to provide expertise for a viable architecture. NASA's Mission Design Teams can be found in the chart below. The Science Mission Design process is described further in Chapter 6. Mission Design Teams, such as the Ames Mission Design Division, conduct early stage concept development and technology maturation for space mission Proposals. Normally, team members have experience in Designing spacecraft and associated Instruments. They might be Systems Engineers, Electrical Engineers and other subject matter experts. [55]

Mission and Concept teams within NASA	
Ames Research Center	Mission Design Division [56]
Jet Propulsion Laboratory	Team X, A-Team [57, 58]
Langley Research Center	Engineering Design Studio, Integrated Design Center [59, 60]
Goddard Space Flight Center	Mission Design Lab, Instrument Design Center, Integrated Mission Design Center [61, 62, 63]
Johnson Space Center	Habitability and Environmental Factors Team, Human Adaptation and

	Countermeasures Team, Space Medicine Team [64]
Marshall Space Flight Center	Advanced Concepts Office [65]
Armstrong Flight Research Center	*No other teams publicly available*
Kennedy Space Flight Center	*No other teams publicly available*
John C. Stennis Space Center	*No other teams publicly available*
Glenn Research Center	COMPASS Engineering Team [66]

Mission Project Design Teams that exist at various NASA Field Centers such as Ames Mission Design Division, while housing Graphic Designers, are not dedicated Graphic Design Teams. [55] This may be an example of individual Designers spread throughout divisions within NASA, sometimes without a specific Design Team. Graphic Designers and Visualization Teams use their skills to help complete the work required for Mission Concept Development and Proposals.

3.2 Design Disciplines within Aerospace

This section describes the key areas within NASA where Design Disciplines can be found contributing to space projects based on information from Chapter 3 (Section 1). Within Aerospace, Design Disciplines can vary widely. Human Space Flight, focusing on humans and their interaction with their environment in space, utilizes Human Centered Design and Architecture when developing their systems. In Software Development, UX Designers and UI Designers are instrumental in the Design of User Interfaces that humans will interact with. JPL's Ops Lab and Ames research center's Usability Design Group are examples of where those disciplines are utilized. Public and Internal

Communication are extensions of NASA's goals of expanding knowledge about the universe. Below is a breakdown of NASA categories that are home to Designers and disciplines that are often found within them.

Human Spaceflight

User Experience, Industrial Designers and Architects work together at Johnson Space Flight Center to develop Architecture and vehicles to sustain life on other planets. User Experience Designers, Industrial Designers and Architects focus on the comfort and experience of individuals interacting with a space. [6] NASA has a long history of Design work through a community of "Space Architects." Many were trained at the University of Houston's Sasakawa International Center for Space Architecture. [67] One example of an Architect working with the space industry can be seen in the work of Guillermo Trotti, an Architect and industrial Designer who supported Design of the International Space Station interior. [68] The role of Architecture spans from habitation, such as the International Space Station to Vehicles and Suit Design. [67] [68] Design questions include Human Factors concerns, including how a space is to be used, interaction with materials and objects, as well as amount of time a human spends in a specific space. Architects in this area look at integration of life support systems, radiation protection, fire safety food and waste management. Russia and China also include Space Architects in their planning, as early as the 1970's which can be seen in the work of Space Architect Galina Balashova and more recently, Long Lehao. [69] [70]

Software Development

Software is used by all NASA Field Centers for Operations of Launch Vehicles, spacecraft Operations and robotic Operations. User Interface Designers, User

Experience Designers and Human Centered Designers are involved when a human is expected to interact with a computer or robotic system. The Jet Propulsion Laboratory's Ops Lab (Operations Lab) and Ames Research Center's Human Centered Systems Lab utilize the skills of User Interface and User Experience Designers within their teams. [71] An example in Chapter 6 (Section 3) provides insight into the importance of individuals interacting with complex software.

Public and Internal Communication

NASA uses Assets such as scientific graphics, illustrations, Animations and videos to communicate science findings to the public and to communicate amongst science teams internally. Graphic Designers, Illustration Designers, Model Makers and Animators are prevalent throughout public and internal Outreach and Communication at most NASA Field Centers. Designers can serve multiple roles. An Illustrator may also be able to Animate or Design graphics. These disciplines may support mission Design and Formulation with their Sketching skillsets. Visualization Teams sometimes create science communication pieces in support of Outreach and communication as can be seen in Goddard and Glenn's Visualization teams. [41] [8] [47] [50] [52]

3.3 Historical examples of Designers in Aerospace

This section shows how historically, Designers have been working in Aerospace since the beginning of Aerospace technology in the early 20th century. The names of disciplines have evolved through time, however basic Techniques and Foundational Education remain the same. The chart below is a timeline created by the author that documents Design from the 1940's through the 2020's within NASA. Information is presented here based on each discipline's earliest documented appearance within NASA as an employment opportunity. Descriptions of these disciplines can be read in Chapter 3

(Section 1). The author used search engines and academic literature to find information. While the timeline below is a work in progress, the history of Design in Aerospace requires more research to produce a conclusive timeline. Future work will need to reference physical documents and assets would need to be referenced and documented from the earliest dates to fully identify the disciplines involved.

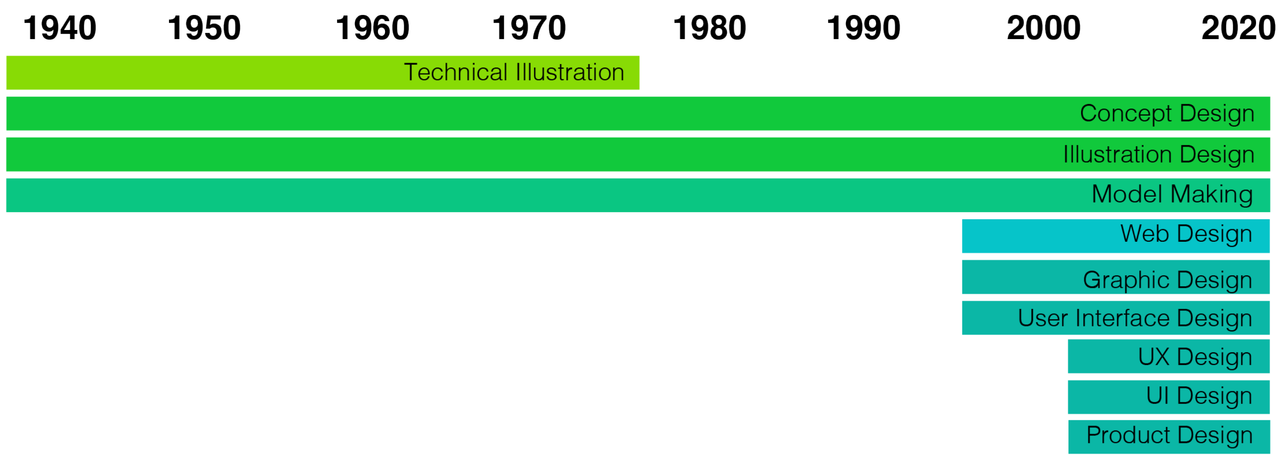


Fig. 5 The NASA Design Discipline timeline in order of appearance.
Image Credit: Lizbeth B. De La Torre

Concept Designers represent one of the earliest examples of Design within Aerospace. Some Designers that frequently worked on Feature Films also worked for Aerospace corporations. The most prominent of these Designers was Chesley Bonestell, who is considered the Father of Space Art.[72] Throughout the 1960's Chesley's work was featured in various publications for NASA. He frequently built small scale models of terrains in order to paint them. [72] Other Designers include Star Wars matte painter Ralph McQuarrie, who illustrated the environment behind our first introduction to Darth Vader after having worked for Boeing as a technical illustrator. [73] He also designed posters and Animations for CBS News' coverage of the Apollo space program. Chapter 7 further details his work. Much like the work of Chesley Bonestell, model makers brought an important skillset to NASA's early years. Model Makers fabricated spacecraft prototypes and scale models from detailed specifications. Today, the only publicly documented model shop within NASA is housed at Marshall's Spaceflight Center. [50]

The Graphic Design Discipline may have appeared much earlier than the 1990's in the timeline above. Since at least the 1920's professionals designed printed products manually, however the author could find no evidence of an official Graphic Design position within NASA prior to 1990. This work may have additionally been contracted out or appeared under a different name, such as "Illustration Design."

One of the first instances of the Product Design Discipline within NASA can be seen in the work of Jessie Kawata at the Jet Propulsion Laboratory. Jessie's work as a former Product Design lead at the Jet Propulsion Laboratory has shown the utilization of the Product Design skillset in development of a smart phone application to track drought indicators. [74] Her work uses the Design Thinking Method in Chapter 4 (Section 1) to improve usability of data through analyzing the hundreds of Methods scientists currently use to monitor drought. The app considers many forms of data relating to drought including meteorological information, soil moisture, vegetation, snow, total water storage, agriculture, ecological, socioeconomic and flash droughts. [74] Jessie's research also showcases the use of tools from the User Centered Design Method such as "Surveys" to inform "multidirectional dialogue". Surveys within this Method are questionnaires that solicit feedback from users. The User Centered Design Method was used within their project to increase knowledge of barriers to the eradication of invasive species in the Earth Sciences field. [74]

As can be seen from the timeline above, the Design Discipline within NASA has been growing in the past few decades and various disciplines have been increasingly involved in technical areas such as Software Design and Human Factors. More literature is needed to develop a more conclusive timeline of disciplines and their roles within NASA.

Chapter 4 | Literature Review of Exploratory Methods and Techniques

This chapter describes Exploratory Methods and Techniques used by Designers within their professional practice. This thesis defines “Exploratory Design Methods” as Methods used by Designers that focus on the compilation, evaluation and blending of both qualitative and quantitative data in a collaborative setting to produce a Proposal or solution to a problem. This definition is gathered from the definitions of the American Association for Graphic Arts, Stanford D. School, and Design firm IDEO. [4] All are pioneers in using Exploratory Design Methods. There are hundreds of Exploratory Design Methods used today. [75] These Methods have been proven to support and improve leading businesses and organizations. Techniques are defined different from Methods. Collin’s Dictionary defines Techniques as a “skill and ability in an Artistic, sporting, or other practical activity that is developed through training and practice.” Techniques include Sketching, Storyboarding, Prototyping and are used to implement the Methods above. Corporations in the past that have had limited Design capabilities are now implementing in-house Design Teams and assigning executive roles to Designers. [76] Design Methods and Techniques are often the foundations of a Design Education. They can be seen as systems and processes for tackling problems. The following Design Methods are documented for their wide use within and outside of Aerospace: Design Thinking, The Disney Imagineering Process, Human Centered Design and Science Fiction Thinking. The author’s reasons for selecting these Methods for analysis in this Thesis are described in Chapter 6 (Section 4).

The tables below briefly define the Methods and Techniques that are explored in this chapter.

Design Methods	
Design Thinking	A non-linear process that emphasizes understanding a user, challenge assumptions and create solutions to problems. [77]
Human Centered Design	A process that aims to make systems useful by focusing on the user, their need and requirements by applying Human Factors. [78]
The Imagineering Process	A process used by Disney Imagineering when Designing theme park Attractions. [79]
Science Fiction Thinking	A process of purpose driven Innovation to develop concepts using science fiction Methods. [80]

Design Techniques	
Sketching	A quick Drawing that is not intended as a finished work.
Prototyping	An early model of a product created to test a concept.
Storyboarding	A drawn representation of a sequence of events.

4.1 Defining Methods

Design Thinking

Designers in the past have focused on improving the Aesthetics and function of objects, however, Designers have recently begun applying their Methods to professional Design work that addresses social challenges. [81, 77] Social challenges require systemic solutions that are difficult to accomplish with other Methods. It involves co-Designing with stakeholders and incorporating input at various stages of a project. Stakeholders are defined by the Oxford dictionary as “a person or company that is involved in a particular organization, project, system, etc., especially because they have invested money in it.” IDEO describes this process as “inherently optimistic, constructive and experiential." It is often thought that IDEO.org evolved the Design Thinking Process, however, as IDEO.org explains, it has history in conversations that have been growing for decades in the Design Discipline. [81] After calls to address client problems out of their traditional scope of Design, normally within the "Human Centered Design Process", IDEO coined the term "Design Thinking" to characterize and categorize the components they found most essential from Human Centered Design. This Method can be broken down as a series of overlapping elements, rather than a linear process. The three big elements of Design Thinking are "Inspiration, Ideation and Implementation". They can be further broken down into these categories: empathy, optimism, iteration, creative confidence, experimentation, and an embrace of ambiguity and failure. [81, 77]

While Human Centered Design is "cultivating deep empathy with the people you're Designing for, generating ideas; building a bunch of prototypes; sharing what you've made with the people you're Designing for; and eventually, putting your innovative new solution out in the world," Design Thinking is "a human-centered approach to Innovation. It draws from the Designer's toolkit to integrate the needs of people, the possibilities of technology and the requirements for business success." [81, 77]

Design Thinking emphasizes a person's ability to recognize patterns, be perceptive and develop solutions that are emotional as well as practical and useful. The IDEO organization believes that an organization with an over-reliance on the analytical and rational bears a risk, similar to an organization that is too reliant on the holistic. [81] For them, Design Thinking is a way of creatively solving problems that "allows non-Designers to think like Designers." [81]

IDEO describes that prior to Design Thinking, there were various works in production describing how Design can contribute to the changing world. [77] Including:

- George Nelson's 1977, "How to See: A Guide to Reading Our Man-Made Environment." This book describes the importance of the human experience in every day objects.

- Robert Mckim’s 1972, “*Experiences in Visual Thinking.*” This shares an experimental approached to visual thinking for Engineering Design.

- Don Koberg’s 1971,”The Universal Traveler: A Soft-Systems Guide to Creativity, Problem-Solving, and the Process of Reaching Goals.” This book can be seen as a blueprint to Design Thinking, 40 years before the term was coined.

Design Thinking can and has been applied to various fields, including K-12 education, Government, Business, Food Innovation, Design Research, Equity Design and Sustainable Futures. [77] The following Institutions contribute to the research and advancement of the Design Thinking Method, including MIT D-Lab, Designmatters at Art Center College of Design, Berkley Haas Innovation Lab, School of Design and Creative Technologies at the University of Texas at Austin, Stanford D. School and Northwestern’s Segal Design Institute. [77]

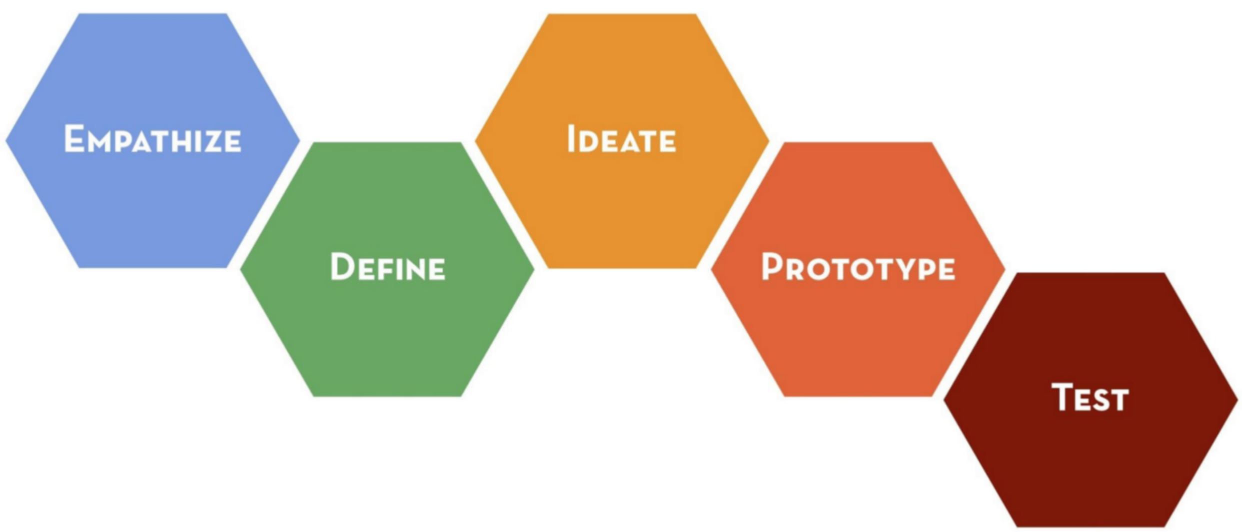


Fig.3 A chart of the Design Thinking Method in practice. Image credit: Stanford D. School

Below, the steps of the Design Thinking Process are explained as defined by IDEO.org and Stanford D. School.

EMPATHIZE

The Empathy Step is about gaining empathy for users of a product or service. During this step designers gather information on how a user behaves, what they need and why certain behaviors, needs and emotions are present. Facilitators for Design Thinking process answers in a "How? What? Why?" format. "What" has happened in the past can be defined, "How" a person is doing what they are doing and "Where" they do it, and "Why" a person is possibly performing an action. [82]

DEFINE

The Define Step is a convergent element of this process. It involves synthesizing the information in the Empathy Step to come to a conclusion about the data gathered. This Step intends to develop a problem statement toward which all future design work is directed. A good problem statement is human focused, allows for creative freedom of individuals involved in the development process, and is clear. [83] The term "Human focused" here means focused on an individual that is intended to be using a product or service.

IDEATE

The Ideation Step is a space for Idea Generation. Through brainstorms, and other approaches to Idea Generation, this provides material for Prototype building and supplying fuel for discussion. Various approaches for Idea Generation are captured by the Interaction Design foundation; a few include: Brainstorming, Braindump, Brainwrite, Challenge Assumptions, SCAMPER, Mindmap, Sketch, Storyboard, Analogies, Provocation, Gamestorm, Crowdstorm, and Creative Pause. [84] Approaches to Idea Generation are described in the table below, referenced from the Interaction Design Institute.

Brainstorming	The creation of new ideas as a group. Often post-it notes are used to capture ideas and group them into key themes in order to reach solutions to problems.
Braindump	This is similar to a brainstorm; however, a participant privately writes down their ideas, and shares them with the group at a later time.
Brainwrite	Also similar to a brainstorm session. Individuals write down an idea onto a piece of paper, and the next person elaborates on an idea. After about 15 minutes of this, a facilitator collects the ideas for discussion.
Challenge Assumptions	This is good for bringing energy back into a lagging session. Discuss assumptions being made about a product's characteristics. Are there characteristics being taken for granted?
SCAMPER	This element is a lateral ideation Technique that uses verbs as stimuli.
Mindmap	Mind Mapping involves a group creating a map of relationships together. A problem statement is at the center of the page, branching out into solutions.
Sketch or Sketchstorm	Instead of writing, ideas are documented in sketch form. Visuals often provoke more ideas.
Storyboard	Create a visual Story relating to a problem that is being solved. Unexpected events can also be documented.
Analogies	Creating comparisons between two things allows for communication of complex matters, for example " A heart and a pump"
Provocation	Provides a mechanism for introducing unconventional thinking by providing stimuli. Stimuli might be an event or word.

Gamestorm	These are gamified blocks of ideation. **The Fishbowl** involves an inner circle of individuals that discuss ideas, and an outer circle that documents those ideas through Drawing and writing. **The Anti-Problem** is the opposite of the real problem a team is attempting to solve. Ideas generated can be flipped back onto the real problem. The Cover Story involves participants creating a headline cover of a Story including images, text, sidebars with facts, etc.
Crowdstorm	the target Audience generates, comments and approves generated ideas.
Creative Pause	Creative pauses can provide a break to reflect on ideas generated.

PROTOTYPE

Designers lead teams in a Prototyping Step after the Ideation Step to observe interaction with low fidelity prototypes of final products. Design Teams obtain significant data in this Step as users interact with the Prototypes. This Step documents the behaviors and emotions of users, and prototypes are iterated on before resources are spent on a high fidelity product. [85] Prototypes in this Step can be made of paper and may be prototypes of a physical object or a software interface. [85]

TEST

Normally, the Test Step occurs concurrently with the Prototype Step. It allows for testing of the Prototypes developed in the previous Step. During Testing, the context and scenario are considered when conducting user tests. This step considers how the Designer interacts with the user and the manner of observing. Observing is done by a Designer visually registering and documenting how a user interacts with a product either in person or through recorded means. Through video recording, users can compare alternatives and experience the product without interference from the observer. [86]

There are criticisms of the Design Thinking Method. The Harvard Business Review provides an overview of criticisms: “that Design Thinking is poorly defined; that the case for its use relies more on anecdotes than data; that it is little more than basic common sense, repackaged and then marketed for a hefty consulting fee.” [87] Award winning Designer Natasha Jen, in her talk titled, “ Design Thinking is Bullshit,” states this of Design Thinking: “ Design Thinking packages a Designer’s way of working for a non-Design Audience by way of codifying Design’s processes into a prescriptive, step-by-step approach to creative problem solving — claiming that it can be applied by *anyone* to any problem.” She argues that “post-it note mania ignores the rich set of tools and Techniques that Designers use to solve problems”. [88, 89] Other processes below emphasize the need for specific Design Techniques such as Sketching, Storyboarding and Prototyping.

Human Centered Design

The Human Centered Design process is very similar to Design Thinking, however while Design Thinking focuses on business practices and societal challenges at a systematic level, Human Centered Design focuses especially on health, human ergonomics and emphasizes Participatory Action Research (PAR). PAR is a research Method that encourages action to understand the environment and attempt to change it after reflection. [90, 91] The definition of Human Centered Design used here is from Design Firm IDEO, the Interaction Design Institute and Stanford d. school. This Method is traditionally used in Design fields that deal with medical devices or software. Notably, this Method is used by NASA Johnson Space Center’s Habitability Design Team when Designing life sustaining vehicles and environments. [48] This Method was popularized by Stanford’s D. School and IDEO.org. [78]

Human Centered Design lends itself to addressing "issues of social justice and inclusion and encourage ethical, reflexive Design." [78] It shares the thematic elements of Design Thinking, but provides greater detail for accomplishing tasks using Design specific Techniques. [78]

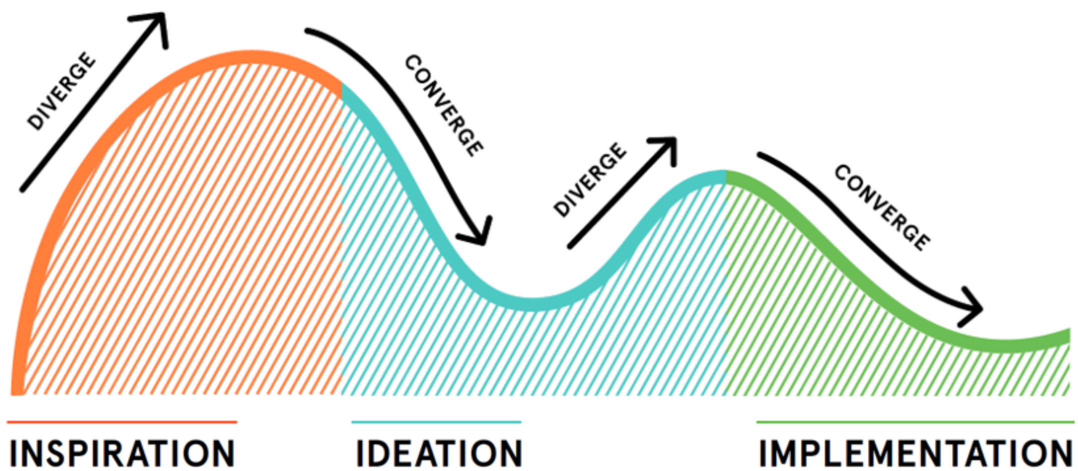


Fig. 4 The Human Centered Design process showing divergent and convergent thinking. Image Credit: IDEO.org, Human Centered Design Toolkit.

Below are the steps in the Human Centered Design Process according to IDEO.org:

INSIRATION

The Inspiration Step is about understanding the problem, observing the challenge and gathering meaningful data from stakeholders and customers about their pains and hardships. This data gathering can be done in a number of ways. Gathering of data can happen from the field or through co-designed information gathering sessions. The Observation Step seeks to gain awareness of the customer as they use the current product, or navigate through a system. Designers lead the participants to create a challenge statement at this point. A challenge statement is a phrase that describes the problem to be solved. At the end of the Inspiration Step is "point of view," which defines the challenge to be addressed after gathering the appropriate data. Information gathered in this Step, such as the challenge statement and observation data is intended for development of actionable steps in the “Ideation” Step. [78]

Active role of the Designer | The Designer is responsible for developing the Methods of data gathering with respect to the clients involved, the business type and challenge to be solved. The facilitator, often another Designer, leads the team through understanding the problem, learning from the users interacting with an object and further defining the challenge to be Designed for. Techniques such as Sketching, Collaging, Photography are valuable at this stage. [78]

Approaches that can be used during the Inspiration Step according to IDEO.org include:

Framing the Design Challenge	Describing the problem to be solved in a way that will drive toward impact.
Creating a Project Plan	Developing the logistics of the project, reflecting on the schedule, staff budget, skills needed and trips. As the project evolves, this plan may change.
Building a Team	Human Centered Design works well with a variety of disciplines. Based on the Project Plan, this section aims to build a team of individuals with varied skillsets.
Recruiting Tools	This section focuses on forming a strategy behind recruiting individuals that will be using the product. A spectrum of behaviors, beliefs and perspectives is ideal.

Secondary Research	This section is for research into historical context, parallel thoughts and products to build a firm foundation of knowledge.
Interviews	Interviews within this Method are done in an individual's space if Designing for a product or software. A person's mindset, behavior and lifestyle can be documented through interviews.
Group Interviews	Community dynamics can be considered with group interviews.
Expert Interviews	Experts are community leaders that can provide insight into relevant context, history and technology.
Defining the Audience	Defining the spectrum of individuals who will be interacting with the product.
Conversation Starters	Suggesting ideas around a specific theme to users to listen to their reactions, comments and ideas. Pre-made cards with printed images are a tool that can be used.
Extremes and Mainstreams	Listening to input from intense users and those in the middle of the target Audience.
Immersion	Spending a day shadowing a user, documenting how they work, how they make decisions- any information that may be important for the project.

Analogous Inspiration	Exploring analogous experiences may help isolate instances of an experience that are ideal.
Card Sorting	This Method can be used to extrapolate the values and wants of a user, and begin discussions about why.
Peers observing Peers	Inviting the people being Designed for as partners in research. They can be given tools to document their behavior, feelings and hopes.
Collaging	When users create a collage, it can say a lot about their values and processes.
Guided Tour	A guided tour through a user's workplace or living space can illuminate habits.
Draw It	Drawing is one Method of documenting research. Users may be asked to draw for example, what they eat every day.
Resource Flow Diagrams	Visualizing resources that come through a household or company can illuminate opportunities for efficiency.

In one example of how these approaches are used, we can examine Card Sorting. Card Sorting allows for sparking conversation about things that matter to clients. Prospective users of a system use a deck of cards with a single word or image on each and rank the cards in order of importance or preference. This is a quick way of determining the values of the user. Deeper explanations of these Methods can be found in IDEO.org's Field Guide to Human Centered Design. [78]

Fig.5 Card Sorting during a brainstorm session. Image Credit: UX Indonesia.

Data collected from the Inspiration section includes behavioral information, values, habits, resources and hopes. Data may be in diagram form, Drawings or images.

IDEATION

The Ideation Step is the divergent element of this process. It involves Idea Generation based on the data from the previous Step such as behavioral information, values, habits, resources and hopes. Quantity of ideas is important in this stage. Designers can co-design this session with clients and stakeholders. At the end of the initial Ideation Step, participants define and vote on Ideas. Ideas should be down selected enough be able to Prototype a few ideas in the next stage. The Prototyping Step is iterative; it can be done on paper and other low fidelity materials. The goal of the prototype is to test a simulation of a product before resources are spent on higher fidelity prototypes. The length of the Prototyping Step can vary depending on the product. Finally, the Testing

Step allows for collecting data on user feedback. Testing can involve context and scenario. [78]

Active role of the Designer | The Designer leads and/or participates in this Step, similar to the previous Step. They coordinate and make others comfortable with using post-it notes for Idea Generation, Collaging and/or Photography. [78]

Approaches that can be used during the Ideation Step include:

Downloading your learnings	Notes, photos, impression and quotes may have been collected in the previous stage. This stage shares these findings with others in the Design Team.
Sharing inspiring stories	This section involves sharing the most memorable stories with team mates.
Top 5	Determine the top 5 themes or ideas that stick out.
Find Themes	At this stage patterns begin to emerge among data collected. Find themes and sort out what they mean.
Create Insight Statements	These succinct statements from users will point the way toward solutions. They can be found within the data. An example insight statement may be: "Individuals who work near a public payphone play a role in directing users toward or away from it."
Explore your hunch	Following the intuitive process of Human Centered Design, this segment allows for following hunches. These can be explored through brainstorms or prototypes.

How might We	Translate the Insight Statements above into “How Might We” questions. These questions turn challenges into opportunities for Design. An example may be “How might we create moments where the community encourages more use of the public payphone?”
Create Frameworks	Draw a visual representation of a system, noting key relationships.
Brainstorm	Promoting openness, quantity of ideas and Creativity over immediate feasibility.
Brainstorm Rules	Defer Judgement, Encourage Wild Ideas, Build on Ideas of Others, Stay Focused on the Topic, One Conversation at a Time, Be Visual, Go for Quantity.
Bundle Ideas	Attempt different combinations of ideas developed in the brainstorm.
Get Visual	Incorporate Drawing, Prototyping and building to make ideas tangible.
Mash-Ups	Combining two different brands to discover new ideas and concepts.
Design Principles	As the ideas emerge, unifying elements that inform the Design also emerge.
Create a Concept	This is the moment where an idea becomes a concept. Based on key themes, bundled ideas and Design principles, a concept should emerge.
Co-Creation Session	Bring community members together to develop a concept with you.
Gut Check	This is an opportunity to look at the concept critically. Discuss with a team what to pursue and evolve.

Determine what to prototype	Discuss with a team key elements of the idea. Document what needs to be tested.
Storyboarding	This process can visualize a product or service from start to finish. It can help define who will use the product, when and how.
Role Playing	This role play allows the Design Team to experience the interaction between the user and the product.

Explanations of these Methods can be found in IDEO.org's Field Guide to Human Centered Design. [78]

IMPLEMENTATION

If a Design at this point is feasible and has produced feedback, it is handed off to those who will be providing the final product whether it be a web application, a smartphone app or a physical object. Storytelling promotes how the product can be used in everyday life. Storytelling is done through visual aids, such as a roadmap or prototype. A product launch is conducted with stakeholders, where the product is deployed and what is likely to become a part of a business model is defined. [78]

The Active role of the Designer I As with other Steps, the Designer supports in messaging, Storytelling and empathy with the user. They may have less of a role in this area as the work is generally shared with those supplying the final product. [78]

Approaches that can be used during the Implementation Step according to IDEO.org include:

Live Prototyping	A live prototype allows for a test run of a product or service out in the real world. It can run a few days or weeks.
Roadmap	A roadmap to implementation can keep the team on track. Responsibilities are assigned as well as milestones.
Resource Assessment	Understand distribution of the solution, partners needed, and capabilities for execution.
Build Partnerships	Identification of funding partners happens in this step and building of relationships
Ways to Grow Framework	This visual exercise can help understand what implementation looks like. This can be a vertical and horizontal axis or other framework.
Staff Your Project	This portion is similar to the building of a team in the inspiration, though this team should be more targeted.
Funding Strategy	This section is for developing long term finding goals and strategies. This may be different than sustainable revenue.
Pilot	A pilot is a sustained engagement, usually longer term and is meant to fully test the product.
Define Success	Setting key milestones can help define what success looks like to the team.
Keep Iterating	Iteration allows for continuing to improve the piloted product based on user feedback and suggestions.

Create Pitch	A pitch is used to communicate to funders, clients, the community or others who may be interested in the product.
Sustainable Revenue	If selling a product, how many does the team have to sell to meet revenue goals?
Monitor and Evaluate	Evaluate why monitoring and evaluating is needed. Is funding needed, or identifying impact? One approach for monitoring and evaluating is a randomized controlled trial.
Keep Getting Feedback	Getting feedback from users is an important process that is done at all phases. There are usually dedicated team members for gathering feedback.

The Walt Disney Imagineering Process

Historically, Disney has been known to utilize the skills of Designers for Concept Generation, the production of illustrations depicting an idea, and Attraction Formulation; the process of developing a ride, resort or themed space. Imagineering is described by Walt Disney as the blending of creative Imagination and technical know-how. [79] Storytelling, Imagination and Creativity are front and center in this process. Storytelling for Disney can mean following a specific narrative when entering a space and emotional influence on an individual. [79] While the detailed Imagineering process may be a trade secret, the following process is a simplified version, taken from publicly available texts on the subject. Each step of the process is defined below.

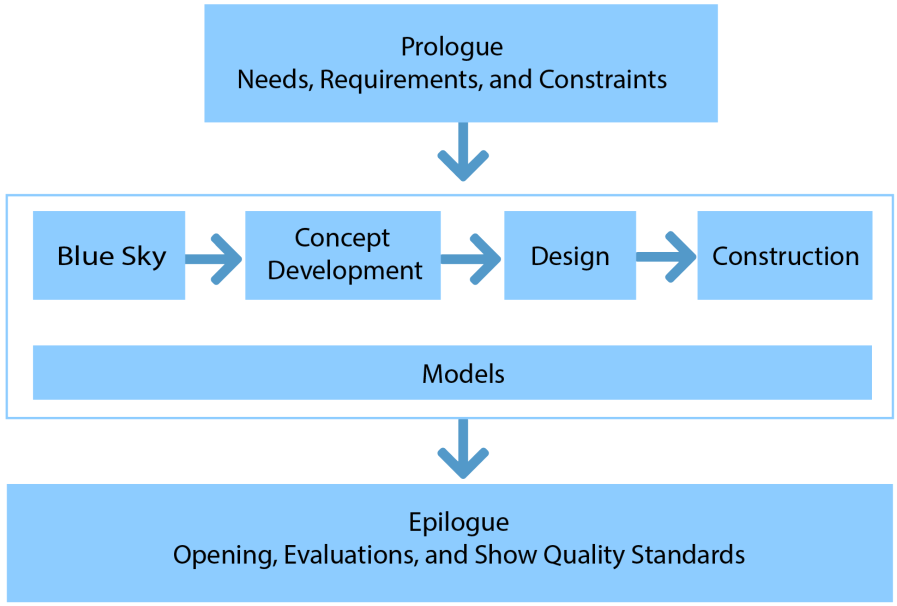


Fig. 6 The Imagineering Process, as described in "The Imagineering Process: Using The Disney Theme Park Design Process to Bring your Creative Ideas to Life." By Louis J. Prosperi. [79]
Image by: Lizbeth B. De La Torre

This process seemingly shares elements with Design Thinking and Human Centered Design, however the end product and disciplines involved vary widely in theme park Design. While Design Thinking is packaged so that non-Designers can utilize the Method, Disney employs hundreds of disciplines, including Concept Designers, Model Builders and experience Designers that provide advanced Techniques unique to the Design Discipline. These disciplines are also present at NASA, definitions of which can be seen in Chapter 3 (Section 1). Perhaps the caliber of the Disney process is enhanced by the advanced level of Sketching, Painting, and diversity of Techniques, leading to more refined visual communication during their development. [2]

It is the combination of the adopted principles and Methods from over 140 disciplines over time that allowed them to develop the Imagineering Process. [2] Information on specific disciplines is not publicly available. While in the past the process was more informal, today it is formalized with specific steps.

The Imagineering process is described below in as much detail as is publicly available.

Prologue Needs, Requirements and Constraints:

In this stage, reflective of the term “prologue” in Storytelling, the project needs and constraints are specified. For this organization, the word “Need” can be defined as a requirement for a new Attraction, modifications to an existing work or sometimes a new theme park. Needs are generally sparked by business and creative motivation. Often, constraints follow needs. Constraints may be defined as budget, physical space availability or schedule. Below are the three goals of this process. [79]

Needs	A requirement for a new Attraction, modifications to an existing piece, a new theme park. [79]
Requirements	Requirements may be the amount of individuals a ride is able to fit, and space needed. [79]
Constraints	Available physical space and budget may be considered constraints. [79]

Blue Sky

The Blue Sky Step of this process is where ideas are generated based on needs, constraints and requirements. While this stage does not have to define the entire scope of the project, budget can be set in this stage. There is also a role for specialists to contribute during Blue Sky. Blue Sky has two stages, including one that is not present in the previous two Methods described in this chapter: Brainstorming and Concept Design. [79, 2]

Brainstorming is defined as generating a multitude of ideas very rapidly based on requirements and constraints. Imagineer Alex Wright describes a set of rules for Brainstorm sessions, taken as direct quotes from literature: [79, 2]

Rule 1: ”There is no such thing as a bad idea. We never know how one idea (however far fetched) might lead into another one that is exactly right.” [79]

Rule 2: “We don’t talk yet about why not. There will be plenty of time for realities later, so we don’t want them to get in the way of good ideas now.” [79]

Rule 3: “Nothing should stifle the flow of ideas. No buts or cant’s or other stopping words. We want to hear words such as “and” or, “What if”?” [79]

Rule 4: “There’s no such thing as a bad idea. (We take that one very seriously)” [79]

Following the brainstorm is Concept Design, where ideas are developed into Proposals. Concept Designers develop sketches and illustrations in order to visualize the intent of a new Attraction. This is often an iterative process, where the sketches spark additional ideas. These concepts can take form in different mediums including Painting, Sketching, Models, written descriptions and pitches. Imagineers use all mediums to create visuals In order to clarify what is being proposed. [79, 2]

Concept Development

In this Step, the core details of a project are defined. A Concept Design is taken and refined enough that development can begin. Concept Design for Disney is as described in Chapter 2; Aerospace also utilizes the work of Concept Designers. Story is the primary driver of the concept development Step. Attractions are dissected according to narrative elements that question how the Audience participates in the Story, time period of the Attraction, etc. [79]

One example from literature describes the concept development of “Big Thunder Mountain Railroad,” a ride at Disneyland in Anaheim, California.[41] The following narrative information was important for Designers during concept development.

- Details about the narrative of the Attraction
- Details about characters in the Attraction
- Information about the environment of the Attraction

Design

This Step can also be called the “Schematic” Step. Architects and Engineers develop construction level plans using the Concept Designs in the previous step. Ride Designs, Facility Designs and Show Designs are the three elements of this stage. Ride Design involves the mechanics of vehicles and corresponding tracks, while building Design involves schematics for the physical space. This section utilizes a variety of disciplines, from Architects and Industrial Designers and Engineers to Electrical, Audio-animatronic, Ride Control and Show control Engineering. [79]

Construction

Construction is the final portion of this process and involves construction crews building the physical spaces and the special props and detailing within the facility or the Attraction. This also involves finalizing the audio soundtrack to be played as guests explore the park. The Imagineering facility in North Hollywood develops set dressings, sets and props. The Attractions also go through a series of testing in this Step. Testing here meaning that Engineering and Design Teams review a ride’s performance. [79]

Models

Models for Disney are physical objects created at varying scales by a skilled fabricator. Modeling is not its own Step here, rather it happens at all stages of the Design process and overlays everything. Models are considered a foundational Technique for Imagineering, important enough to have their own Step in the process. Models are built physically. In Disneyland's earliest days, animators used their Color Theory and Shape Language Techniques and applied it to the three-dimensional space. Color Theory and Shape Language are part of a Foundational Education in Design and are described in Chapter 2. Walt Disney has said of this process, "a model may cost $5,000, but it's sure less expensive than $50,000 to fix the real thing." The models are low fidelity at first, made from foam and increase in fidelity as the concept develops. These models can also be considered Prototypes as defined in Chapter 4.2. [79, 2]

Epilogue: Openings, Evaluations and Show Quality Standards

The last part of the process can be described as the observation and maintenance portion. Observation here means documenting queue wait times, Audience reaction and activity within the parks and resorts. Disney uses technology such as the "MagicBand", a wearable wrist piece that allows for financial transactions and access to resorts. [92, 93] Smartphone applications used within the park for navigation are also used to provide guests with park information. [94] An Attraction at the Epilogue stage is evaluated and maintained by the parks department and has been handed over for park management. [79]

Science Fiction Thinking

Science Fiction Thinking is a Method and term coined by Perception Studios. [80, 95] Perception Studios is a Design Firm that imagines and develops the futuristic technology seen in Feature Films, such as Black Panther (2018) and Iron Man (2004). Their process involves extrapolating technology innovation through Storytelling and World-Building. Storytelling here means creating a narrative, while World-Building means crafting an imagined environment through which a technology is intended to be used. An example of this is the World-Building guide for the Feature Film Black Panther. [96] Designers create a World-Building guide when a film is in development. Through this World-Building guide, any technology or Artifact created for the film contains narrative elements that imply the Artifact exists within that world. While this Method has its roots in Feature Film, Perception Studios has recently begun applying their Technique to Aerospace corporations as they have discovered that Design for film can be supportive to other industries. [80]

An MIT course titled, "Science Fiction- Inspired Envisioneering and Futurecrafting," or "Science Fiction Fabrication," emphasizes a variation of this Method to create technology through "critiques of classic and modern science fiction, data-science extrapolation, digital and experiential simulation, evocative Design Imagination and holistic integration of select elements." [97] The MIT course, led by Dr. Dan Novy [98] and Joost Bonsen, [99] utilizes proven technology extrapolation Methods, such as the "Zwicky Box" and the "Artifact from the Future" to allow students to fabricate and reverse Engineer Artifacts from Feature Film. [100] From the class, ideas such as Spiderman's "Spidey Sense" come to life through working prototypes. [101]

Below is a breakdown of the Science Fiction Thinking Method as popularized by Perception Studios:

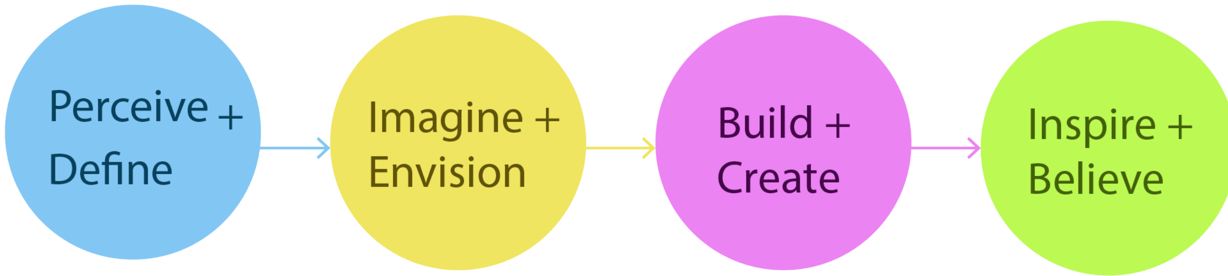


Fig. 6 A chart depicting the "Science Fiction Thinking" Method as defined by Perception Studios. Image Credit: Lizbeth B. De La Torre

Perceive + Define | Hear

Because of its roots in Feature Film, much of the terminology in this Method is reflective of the world building seen in movie production. The first portion of this Method focuses on understanding "Story" and "Characters." Story here means the desired narrative of a product or technology. Characters can be defined as users of a technology. The Perception Studios team imagines the world a technology may inhabit in order to discover problems, use cases, desires and emotion in the work. At the end of this step, the problem is fully "perceived." Perceived here meaning envisioned and understood. [95]

Imagine + Envision | See

This step has similarities to the Imagineering Methods above, where a "movie set" is envisioned in the mind without regard to resources, budgets, constraint. This step imagines a future society using the product or service. It heavily involves Techniques from the Design Discipline. Sketching, doodling, collecting of imagery are highlights of this Idea Generation phase and heavily emphasizes visuals. Sketching and doodling are described in Chapter 4 (Section 1) as a quick, informal Drawing Techniques. Collecting of imagery is a form of visual research used by Designers where graphical references are used as inspiration. [102] This emphasis on visuals echoes the Concept Designers involved in the early stages of the Imagineering process and those working in Aerospace as described in Chapter 2. Perception Studios does not use the word "ideating", and prefers the term "World Building" for this stage. [95]

Build + Create | Touch + Feel

This stage allows an idea to be "experienced," similar to the Design Thinking prototype stage and role playing Method discussed earlier in this Chapter. Perception Studios refers to their prototypes as "Experience Prototypes." These prototypes are developed to be as real as possible, with users able to interact with the product. The prototypes are used as conversation starters to discuss the future world a product will reside in, and possibly recognize when a future should be avoided. They emphasize "reverse Engineering science fiction." [95]

Inspire + Create | Smell + Taste

The final stage is meant to provide a product "so real you can smell it, you can taste it." [80] An ideal final product should inspire feeling or emotion. Using their final prototype should provide a way to green light a project or guide Engineers toward a future product. [95]

4.2 Defining Techniques

This section describes Techniques used by Designers in parallel to the Methods above. The Techniques below describe Sketching, Prototyping and Storyboarding, which are Visualization and Communication Techniques used by the different disciplines in Design. There are variations of all of these Techniques, such as different forms of Sketching, Prototyping and Storyboarding specific to different disciplines. These Techniques are often included in the Foundation Education of Designers and follow them throughout their careers. Engineering Disciplines have not been seen to emphasize an Arts foundation in their foundational studies. The Methods above all emphasize using the Techniques to be discussed in this chapter.

Sketching

The word “sketch” can be described as a loose, quick Drawing that is intended to quickly get across an idea, but is not a finished work. [103] Sketches can be created in any Drawing medium, digital or analog, however it is most often associated with pencilwork, charcoal or pastel. Various disciplines of Design emphasize the use of Sketching to communicate an idea visually. [103, 104]

Fig. 7 Rembrandt, A Satire on Art Criticism*, 1644, pen and brown ink, The Metropolitan Museum of Art, Robert Lehman Collection, New York, inv. no. 1975.1.799*

There are various forms of Sketching specific to different Design Disciplines. Industrial Design, Fashion Design, Entertainment Design, and Architecture all emphasize specific Shape Languages, knowledge and skill in their sketches. Sketching is often said to be a language through which a Designer can facilitate dialogue with others. [104] Doodling is a term related to Sketching, though can be described as an even simpler graphical representation drawn when a person’s mind is idle. [105] There is research that shows the significance of the Sketching Technique. A study by Dr. Maria Yang at MIT hypothesizes that “not all Sketching skills are related equal in the context of the

Engineering Design process," implying a difference in Design outcome concerning sketch quality. Additionally, her research shows that quantity of Drawing may correlate to higher skill level in Sketching while focused on the Engineering Design process. [9]

Designers often use Sketching at the beginning stages of a Product Design. The Design curriculum emphasizes Sketching and Drawing as an educational foundation. The Engineering curriculum in the United States focuses on the teaching of drafting and CAD, which is normally used when a product concept is at a high fidelity. The Engineering curriculum does not emphasize Sketching for the first stages of Design, when it is important for an idea to be malleable. [10, 9] The work of Dr. Yang suggests that Engineering institutions should be informed of the type of Sketching being instructed and how it is distinct from drafting, which focuses on realistic Drawing. Sketching is necessary as a communication tool, with similar value to other languages such as math and verbal language. [10] An early example of Sketching applied to Engineering may lie in the work of Leonardo Da Vinci, whose work is admired today for both Artistic Painting and Engineering excellence. [106]

Research shows a statistical significance in the correlation between quantity of sketches and Design outcome in Idea Generation and Brainstorming. [9] Dr. Maria Yang at MIT, investigates Concept Generation through brainstorming, morphology charts and Sketching. [9] The quantity of Drawings created during the earliest stages of the Design process were found to correspond to Design outcome. [9] Her work utilizes Sketching categories defined by Engineering researcher Eugene Ferguson for academic purposes, however Designers in the professional Design practice as described in Chapter 2 do not utilize this categorization to guide their education. These categorizations are not reflective of stylistic differences within Design Disciplines. [104]

Sketching Categories	
Thinking sketch	Used to guide and focus nonverbal thinking.
Prescriptive sketch	Intended as a higher fidelity sketch for production purposes.
Talking sketch	Created during technical exchanges to clarify information.

The chart below describes the stylistic differences of the Sketching Technique within the professional Design practice that is referenced in Chapter 6 of this thesis. These discipline specific sketches are described because their educational foundation courses emphasize a specific style of Drawing. The author could find no evidence of other Design Disciplines in the professional Design practice that emphasize specific styles of Sketching.

Sketching Styles	
Industrial Sketching	This form of Sketching is for products intended to be manufactured. There is an emphasis on lines of an object profile and material emphasis, such as the shine of glass. They may be accompanied by annotations describing materials. [107]
Entertainment Sketching	This form of Sketching emphasizes characteristics of Characters, environments, vehicles and objects through exaggeration of perspective, material and shape. It is meant to convey an idea, emotion and Story. This Sketching Technique equally emphasizes the Drawing of objects, vehicles, humans, animals and environments. These sketches may be used for Film, Animation and Video Games. [108, 109]

Fashion Sketching	This Sketching Method has an emphasis on garment Design. Figures are often exaggerated to define the fluidity the wearing of a garment. Materials play a large role in this Sketching Method. This form of Sketching is often accompanied by discipline specific language defining stitching placement and style of clothing. [110]
Architecture Sketching	This style of Sketching is for building Design. It emphasizes user flow, aspects of a space that require interaction, and may be accompanied by discipline specific annotation. [111]
Transportation Sketching	This style of sketch is for the development of vehicles. Ergonomics may also be Designed. It emphasizes Aesthetics of emotion through Shape Language and Color Theory when Designing a vehicle. This Sketching can include any vehicle that will transport people. [112]

Prototyping

A Prototype is considered a low fidelity model of a product used to test the object, obtain user feedback or communicate a concept. It is used in various disciplines, from Design, Engineering, Software and Electronics. In the Methods discussed in Chapter 4 (Section 1), Prototyping has been described as essential in the phase of going from idea to final product. [113]

Designers can build Prototypes with media, however, they normally use lower quality materials. The Imagineering process uses models made of clay and foam to Design Attractions, while in Software Development, paper products may be used. Engineering Disciplines may define Prototypes as higher fidelity than the Design Disciplines. [114]

Storyboarding

Storyboarding can be considered an organizational series of illustrations formatted in chronological order to depict the Story of a film, Animation or experiential piece. A Story is a narrative account meant to describe a person or events. Walt Disney Studios refined Storyboarding in its current form in 1930. [115, 116] It was Walt Disney that developed the first "Story department," within an Animation studio, with a dedicated Storyboarding Discipline after recognizing the importance of emotion and narrative to Audiences. [115] All Animation studios today utilize Storyboarding.

Most recently, Industrial Designers, Experience Designers, UX and UI Designers utilize the Technique in a format that is used to define how a customer is expected to use a product or service. These disciplines are described in Chapter 2. Designers within these disciplines create detailed Storyboards describing body movement and emotion of a user utilizing a product. It is also used in scientific research, often in linguistic fieldwork. A subject is provided with illustrated representations of objects or situations and then implored to describe it. [117]

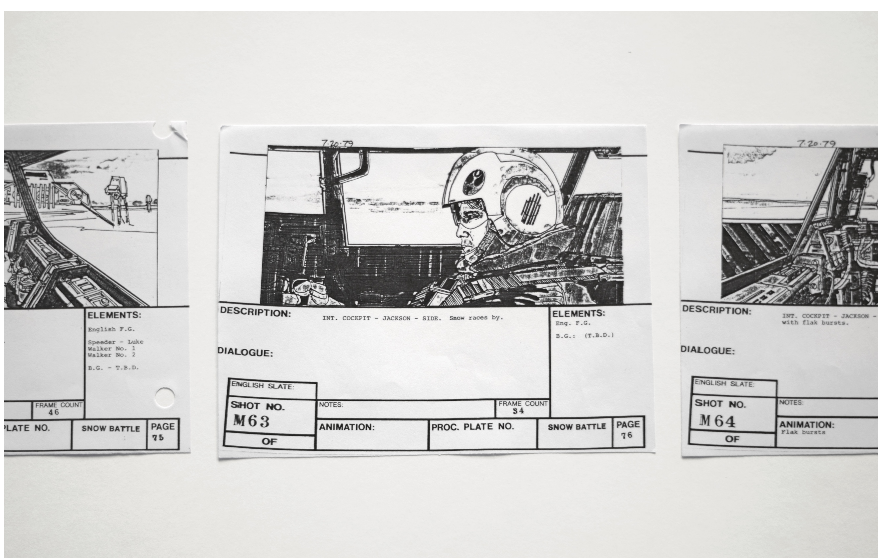


Fig.8 Storyboard reference copies used on set during the filming of The Empire Strikes Back in 1979. The original Storyboards were created by Designer Joe Johnston.

Image Credit: Matt Popovich

4.3 Methods and Techniques Catalogue

This section shares the beginning of a catalogue of Design Methods and Techniques for use in the Aerospace Industry. The following chart is in a format developed by the Netherland's Design Institute. It breaks down Methods and Techniques described in Chapter 4 (Section 1) of this thesis. Input is also documented, meaning the intended amount of time, disciplines required and amount of staff needed to support a project through estimated gauges. [12] In light grey below, other prominent Design Methods that are not discussed in this thesis are listed. Expertise, Time, Staff and Cost bars are grey where data could not be found.

Legend of Definitions	
Expertise	The number of individuals needed that are subject matter experts.
Time	The amount of time the process takes from start to finish.
Staff	The total number of personnel needed, including experts.
Costs	How much this Method costs to utilize, considering amount of paid staff and not counting travel.

Methods Chart | Design Methods and Techniques

Design Thinking: Input referenced from IDEO.org and the Interaction Design Foundation [77, 81]

Human Centered Design: Input referenced from “The Human Centered Design Toolkit” [78]

Science Fiction Thinking: Input referenced from the website of “Perception Studios” [80, 96]

Imagineering Process: Input Referenced from literature on the subject where available. [79, 2, 32]

Method *The Methods mentioned in this thesis are listed below*	Page *Where the descriptions appear*	Techniques *Associated Techniques are listed below.*	Output *These give the main benefit to the design team*	Input *Rescourses Needed*			
				Expertise *Low – High*	Time *Low – High*	Staff *Low – High*	Costs *Low – High*
Design Thinking	32	Sketching Prototyping	Idea Generation Behavioural Data	■■□□□	□□□■■	□□□■■	□□■□□
Human Centered Design	36	Sketching Prototyping Storyboarding	Enhanced sensitivity to users Product Design	□□■■□	□□□■■	□■■□□	□□■■□
Science Fiction Thinking	45	Sketching Prototyping Storyboarding	Idea Generation Viable Product Concepts	□□□■■	□□□■■	□□■■□	□□■■□
Imagineering Process	41	Sketching Prototyping Storyboarding	Product Concepts Enhanced Storytelling	□□□■■	□□□■■	□□■■□	□□□■■
User Centered Design	--						
Interaction Design	--						
Experience Design	--						

Chapter 5 | Investigation of Exploratory Methods and Techniques in Industry

My research question is: What Exploratory Design Methods and Techniques are currently utilized formally and informally within Aerospace and what barriers and opportunities exist to expanding these Methods and Techniques?

This chapter includes summaries of data collected from personal interviews with Designers and Engineers within and outside of Aerospace in order to answer the research question above. The summaries are written as Analytical Narratives. The questions asked that inform the written prose below are described in Chapter 1 of this thesis. Codes are used to protect the privacy of individuals and organizations. It is the intent of the data to shed light on opportunities where Design is supported in technical institutions and where Methods and Techniques are utilized. It is expected that Designers use some form of systematic process in their problem solving and utilize Design Methods and Techniques. The Analytical Narratives may include historical supportive evidence.

Key findings include evidence of Design Methods and Techniques being utilized within Aerospace. Evidence shows that a barrier for Aerospace Designers includes a lack of knowledge about the Design Discipline among colleagues of an Engineering Discipline.

5.1 Research Design

This thesis aims to develop a taxonomy and Design language for use in Aerospace through exploring the space mission development process and Designers that work in parallel fields outside of the Aerospace Industry. A research Design using case studies allows for developing data patterns through referencing of historical documentation, anecdotal evidence and in-person interviews.

This research design consists of a multi-case study including direct observation and personal interviews. The case study is unique in its ability to catalogue a wide variety of evidence, including artifacts, documents, interviews, and observations. The author selected a case study approach for this work because the data being documented is happening in the present time period and includes information that is not able to be replicated in a laboratory setting. [118] An experiment based on my research question would not be beneficial because of the separation from context and focus on few variables. [118]

This research Design makes use of qualitative data from in-person interviews through coding and patterning from use cases. After collecting information from the interviews, the author searched for key themes that arose from the data that supported the research question. Data was grouped into these arising key themes. It was expected that Aerospace organizations would not have as clear an understanding of the value of Design because of anecdotal evidence from public interviews from NASA Designers. [7] Little literature exists on the topic of Design Disciplines within Aerospace. This work is not meant to test a hypothesis, rather, to build an early foundation from which to develop potential theoretical statements about the research question.

These Methods are relevant to this work in their capacity to collect personal experiences and views of people with in a variety of disciplines. Other Methods, such as closed question surveys do not allow for the nuanced discussion and anecdotal findings this thesis hopes to gather. In attempting to understand cultural and societal barriers, the ability to gather historical evidence is preferable. [118]

The units of analysis were constrained to organizations. Data collected from employees was compared across organizations, including perspectives of organizations concerning the Design Discipline. The author began by collecting qualitative data through a series of personal interviews with a variety of stakeholders within individual companies.

These interviews to collect from Management and Line employees. The units of analysis supported defining the dynamics of the relationships, understanding why opportunities do or do not arise and dissect the culture of individual companies. The author received permission from current contacts at these institutions to interview their staff. Personal and virtual Interviews allowed for gaining qualitative insight into an organization's structure. Through personal and virtual interviews, it was hoped to gain additional insight into their Methods that may not be attained in surveys. Closed Question surveys do not provide a way to gain additional insights and written text may imply a more permanent statement. In order to gain both opinion and factual information, personal interviews were optimal.

Answers to the research question were supported by data summarized in Chapter 5 (Section 3). Data shows evidence of Design Methods being utilized within Aerospace and evidence of an unclear understanding of the value of the Design Discipline that may imply a barrier for Designers in this field. Evidence from interviews also suggests opportunities for utilizing Design Methods and Techniques within Aerospace. The Sketching and Prototyping Techniques were found to be most utilized outside of Aerospace in this data set, while elements of Design Methods were referenced sparingly.

5.2 Case Study Protocol

The Case Study as used in this thesis is an in-depth study of an event or episode regarding an individual. It gathers empirical data on an event, circumstance, experience and phenomenon. Especially relevant for this thesis is the Case Study's ability to gather data and evidence from multiple sources; persons, decisions, periods and policies can be analyzed through the Case Study. [118]

Information Gathered

The Case Studies in this thesis were developed to gain insight into Exploratory Methods and Techniques and their use in organizations. Instances were these Methods are supported, indications of multidisciplinary work, and support from the organization are attained in the questions within the case studies. Questions are written broadly enough that an individual may answer and speak within the nuances of their role. It is expected that while individuals may not use clearly defined Exploratory Methods and Techniques, they may use Techniques and Methods that align with a certain Methodology's guidelines.

Data Collection Plan

Through In-person and virtual interviews, it was hoped specific questions could be answered by the individual. The questions were modified slightly for the different roles I hoped to gather information from: Design, Engineering and Management. In a few cases, an individual fulfils two roles, in which case it is noted in the analyses.

Data was collected through audio recordings and transcribed with audio to text software, Otter.ai. [119] Recordings and transcribed information will be stored on an MIT Media Lab computer until June, 2021.

Analysis of Data

Transcribed prose was color coded, depending on whether evidence points to answering the first or second half of the research question. [118] Barriers, opportunities, tools, Methods, Techniques and support were all taken into account as well as discipline. A table following each case study is meant to clearly identify any tools and Methods used or indicated.

Evaluation

For Evaluation, the author referenced Robert Yin's criteria for judging the quality of research Designs for case study research. [118] Particularly, construct validity, internal validity, reliability and external validity. [118] The data collected from this thesis was obtained from multiple sources of evidence to support construct validity. Evidence was collected from Aerospace organizations that have proven to have a high launch rate. Data was also collected from organizations outside of Aerospace that show support of collaboration of Engineers and Designers. Internal validity is achieved through the extrapolation of key themes from the data, defined as pattern-matching. [118] Through using a categorization Technique supported by The Netherlands Design Institute, the Methods and Techniques explored in this thesis can remain unbiased in the active role of the Designer within each Method and support reliability by creating a database, or in my case, Design library and taxonomy. [12]

External Validity came in the form of separate interview-based reviews with leaders in Aerospace firms. The author expected new perspectives concerning these Methods and Techniques based on the work collected for this thesis. Ideally, success is determined through evidence of a new understanding of these Methods and the clarity for implementation within their respective institutions and processes.

5.3 Interviews

Company A | Entertainment

Interviewee: Employee 1

Position: Industrial Designer, Management

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Story	A narrative describing an event, involving Characters and environment
Aesthetics	A branch of philosophy involved with beauty and Artistic taste.
Attraction	A ride at an amusement park. This term includes roller coasters, flat-rides, games and other elements of amusement.
Audience	Customers who will be using an Attraction.

The author conducted this interview before a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

This company has been known to be historically supportive of the Design practice. The Industrial Designer Management role is involved in the beginning stages of the ride Design process and frequently works very closely with other disciplines. Employee 1 co-leads a creative writing Engineering studio. Employee 1 focuses on core function principles. This employee also informs Aesthetics. They are involved in most projects, defining what the narrative and creative intent are of a project. Visual aspects of a ride move forward with mechanical aspects of the Design in parallel. Both Aesthetics and mechanical aspects of an Attraction are informed by the Story. Engineering does not drive everything in Attraction Design; creative intent plays a key role in Attraction development. Employee 1 mentions that first and foremost, Company A is not an Engineering firm and highlights that while there is a collaborative nature of disciplines within this organization, it is primarily driven by Design. The Engineering is often hidden from the Audience in the final Attraction and there is an emphasis on comfort and emotion.

Most collaboration happens on campus, or in a physical space. Teleconferencing is avoided when possible. This is important for the various brainstorms that happen day to day. These brainstorms are focused on challenges, often based on options and associated impacts of decisions. Designers consider in great lengths the end user, or Attraction operator who will be maintaining the Attraction. There is often a representative that can provide input from the parks operation perspective. In his words, this is similar to Design studios where brainstorming sessions involve various stakeholders.

Employee 1 mentions that what makes the Company A project development process advanced is that all Design Disciplines are in-house, where other Design institutions may contract work out. By housing all disciplines, there is more collaboration and this reduces work being "thrown over the fence." There are details and nuances that allow Company A to hire specialists versus generalists. He highlights the work of materials experts, plastic experts and concrete specialists. Employee 1 believes this integration of disciplines allows for efficiency.

Barrier:

From Employee 1's work in Aerospace, he has seen the opposite end of the spectrum in firms that are primarily driven by Engineering. He explains that in some ways Engineers within Aerospace discredit the value of Design. While these firms excel at the utility of a product, they do not realize the significance of emotional impact and explains that Design is certainly difficult to quantify as there are no equations, and it is not a linear process. He mentions that Design is perceived as more subjective, even though he thinks a lot of it isn't. Company A recognizes the intangibility of the Design process and understands that it works.

Methods and Techniques:

While Employee 1 uses brainstorming Methods and Techniques such as Drawing, Sketching, Storyboarding as described in Chapter 4 (Section 1), they do not use dedicated Methods such as Design Thinking. Employee 1 prefers to use elements and portions from the Method such as card sorting, Idea Generation and other Methods described in Chapter 4 (Section 1). He mentions that in his area, the Design Thinking process is difficult to utilize because of differing time horizons within projects, however their R&D department may be more likely to utilize formalized Methods. Their objective is to innovate without the strict time constraints of Attraction Design. He thinks for the most part, Designers are strategic thinkers. Company A, similar to Aerospace corporations, relies on previous knowledge and Design to inform current projects. Within NASA this is called "heritage." [120]

As for Techniques, Employee 1 uses Prototyping and Industrial Design style Sketching as defined in Chapter 4 (Section 2) for visual communication, often on a whiteboard during brainstorming. Tools of choice include a Cintique tablet, [121] Adobe Photoshop, [31] pen and pencil. It is not rare to see sometimes hundreds of Drawings for ride Attractions that describe every detail of the vehicle. He emphasizes not Designing in 3D software because it does not make efficient sense. He can produce 50 Designs on paper in the time it takes to produce one 3D model. Often however, a Design is plugged into Solidworks to serve as a "base" model that will then be drawn over. [21]

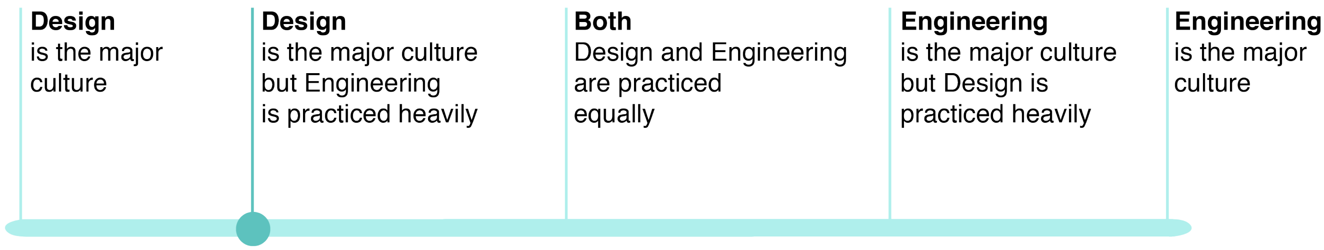
This chart categorizes Methods, tools and areas where tools are used based on this interview.

Methods	Tools	Areas Used
Imagineering Process	Pen/ Pencil/ Paper	Industrial Design
Elements of Design Thinking	Adobe Photoshop [31]	Ride Vehicle Design
	Solidworks [21]	Schematics
	Rhino, Grasshopper [122]	Brainstorms
	Pen, Pencil, Paper	Ergonomics
	Alias [123]	Proposals
	Matlab [124]	
	AutoCAD [20]	
	Cintique [121]	
	Revit [125]	

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

This gauge captures the cultural value of an organization on the topics of Design and Engineering. One end of the gauge implies an emphasis on Design; the other end of the gauge emphasizes Engineering. This gauge is based on historical evidence and interviews.



Company B | Aerospace

Interviewees: Employee 1

Positions: Spacesuit Integration Lead, Flight Test Engineer, Flight Crew Operations and Flight Test Director

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Design Analysis Cycle	This Is an Engineering Method of applying ongoing evaluation tasks to existing projects.
Flight Projects	This is a term for space architecture Designs that will be launched on a rocket into outer space.
Operations	This term describes technical activities after a space project has launched.
Testing	This term is the evaluation and analysis of a project.

The author conducted this interview before a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

Employee 1 begins by stating that Company B uses the NASA Systems Engineering model for any Space Programs their team works on, beginning with Design Analysis Cycles. [126] There is a collaborative effort between Designers and Engineers as they go from requirements, to Design, to verification and validation. Employee 1 works on Flight Projects, Operations and Testing. Operations and Testing involving Employee 1's discipline is largely Human Centered Design focused. Human Centered Designers work on anything an astronaut may touch or interact with during a space mission or training. Astronauts interact with spacecraft controls, tools, personal care items and science experiments. Frequently, Employee 1 works with Human Centered Designers, where the Designer may be creating an item for use, and then approaches Employee 1 about whether the Design is sufficient for the operators (or astronauts). Employee 1 provides the Human Factors Analysis. Their job experience is with Company B and Company G and they have noticed that Company B has a budget line item specifically for Innovation, where Engineers are provided with funds to pursue rapid prototypes before honing in on a specific Design. Employee 1 states that providing budget for prototypes mitigates a lot of risk upfront.

Methods and Techniques:

In their work, Employee 1 uses various Methods, including Design Thinking, Human Centered Design and Science Fiction Thinking as described in Chapter 4 (Section 1). In one example of their work with Science Fiction Thinking, Employee 1 mentioned their PhD Dissertation, where they were inspired by the suits of Batman and Spiderman to develop a spacesuit material that repels moondust. They additionally mentioned using Human Factors Qualitative Assessments in their work.

Employee 1 uses Sketching and Prototyping as defined in Chapter 4 (Section 2) quite often. The style of Sketching and Prototyping were not mentioned. They alternatively use photographic references in their note taking, opting to find images to inspire projects online. [102] Additionally, Employee 1 uses Powerpoint to collect information and present work. [127] In the cases where they do not have the tools to produce assets, they will go to Company B's Creative Services Team. The Creative Services Team supports Engineers with Photography, Journaling and Science Illustration (for publishing or public announcements). Employee 1 states that in general, there is support for her work from upper management. Employee 1 splits support into two areas, verbal and financial. Verbal support is in the form of spoken acknowledgement. Financial support is in in the form of budget allocations.

Barriers: None Mentioned.

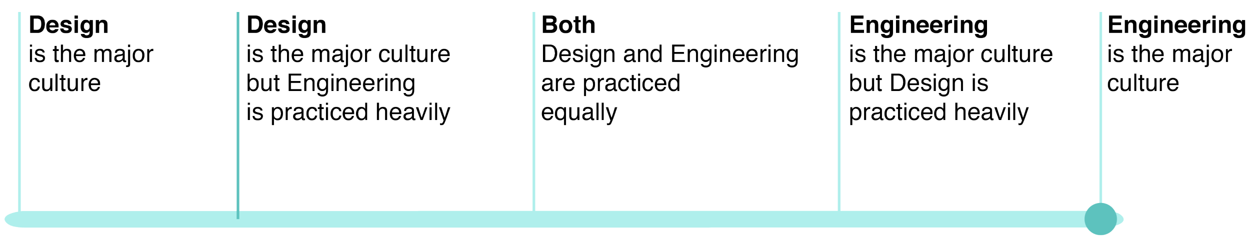
This chart categorizes Methods, tools and areas where tools are used based on this interview.

Methods	Tools	Areas Used
Human Centered Design	Pen/ Pencil/ Paper	Industrial Design
Design Thinking	AutoCAD [20]	User Centered Design
Science Fiction Thinking	Powerpoint [127]	Human Factors
		Proposals

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

This gauge captures the cultural value of an organization on the topics of Design and Engineering. One end of the gauge implies an emphasis on Design; the other end of the gauge emphasizes Engineering. This gauge is based on historical evidence and interviews.



Organization C | Aerospace

Interviewees: Employee 1, Employee 2

Positions: Graphic Designer, Graphic Designer

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Proposal	This is a term for a document of a plan provided to NASA Headquarters by a field center for funding consideration.
Communication	The exchange of facts or noteworthy information.
Story	A narrative describing an event.
Mission development	The act of developing a plan for implementation of a space mission project.

The author conducted this interview before a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

Organization C is a federally funded research center. Primarily, it focuses on the manufacturing, development and operation of robotic spacecraft.

Employee 1 and Employee 2 are two Designers within Organization C who help Engineers develop their ideas utilizing various Design Techniques such as Sketching and Prototyping as defined in Chapter 4 (Section 2). There are various Design Disciplines within their department, including Graphic Design, Illustration, Advertising, Industrial Design, Motion Graphics and Entertainment Art. Both Employee 1 and Employee 2 describe their brainstorming practices as welcome by the Engineering community. Engineers craft Proposals for funding and may face challenges concerning communication of a mission's Story to colleagues or the public. Employees 1 and 2 Design key illustrations and develop a Story as part of a space mission team. The Proposals are for entire robotic space missions, typically costing between 100 million to 1 billion dollars. Employee 2 mentions that Proposal teams comprised of Engineers are sometimes looking for something to make their work visually different from others.

Employee 1 uses sketches and imagery to visualize what the challenge is. Designers also as ask questions that Engineers are unlikely to ask when they discover potential solutions. This echoes the Design Thinking Method in Chapter 4 (Section 1), though it is not generally followed as a formal process; elements of Design Thinking may be used to discover potential solutions. Employee 1 describes that this also applies when communicating scientific information to the public. Scientific information can include research data, imagery collected from spacecraft and public events.

Often, a Designed illustration or other form of visual communication is necessary for sharing information with the public. In the past, sculptural works and technology pieces were created to communicate scientific information. Collaboration with Engineers happens often. Employee 1's experience is in objects and installations, and the process begins with Story and Audience.

Barriers:

When asked about Organization C's historical support of Designers, Employee 1 mentions that Organization C may not have been historically aware of how Designers could support Mission Development in the past, but the idea of Design and Technique is slowly catching on. They would not say that they were unsupportive, rather, unaware of Design terminology and skillsets.

Methods and Techniques:

Employee 1 states that Organization C is advanced as a technology organization because of its risk taking culture that allows for new Methods to be tested. Employee 1 implies that Creativity is fostered through multiple disciplines working together to solve space mission challenges. Employee 1 describes the Techniques they use most as Sketching as described in Chapter 4 (Section 2) and Photography. They also edit in Adobe Photoshop [31] to produce visual elements alongside Keynote [128] presentations for pitches. Employee 2's focus is on Storytelling and their process is more organic. They utilize a note taking structure that emphasizes organization of information to frame project ideas and tasks. They also pull from photographic imagery for inspiration and utilize Keynote for pitches and idea organization.

In a department project funded by Organization C's "Center for Innovation", the author co-led a study with Employee 1, where Design Thinking was the primary Method of data collection for the research project. It involved two astronauts, heads of relevant private corporations, leading Mars Engineers and one Concept Designer from the Entertainment Industry.

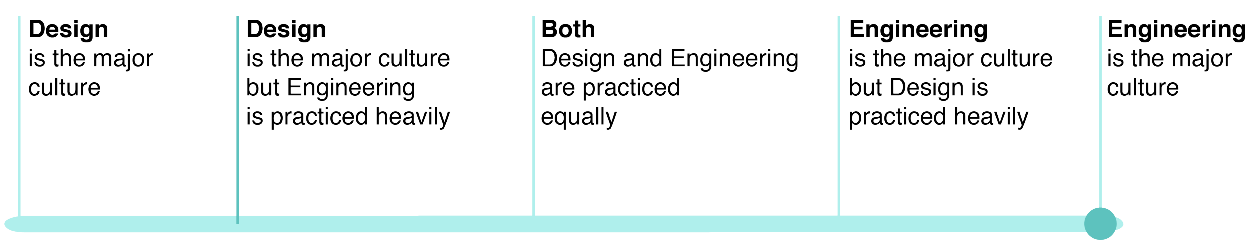
This chart categorizes Methods, tools and areas where tools are used based on this interview and the author's experience.

Methods	Tools	Techniques	Areas Used
Design Thinking	Pen, Pencil, Paper	Sketching	Graphic Design
Human Centered Design	Adobe Photoshop [31]	Drawing	Architectural work
	Cinema 4D [129]	Photography	Schematics
	Paint	Prototyping	Brainstorms
	Wacom Tablet [130]		Proposals
	Adobe After Effects [131]		Pitches

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

This gauge captures the cultural value of an organization on the topics of Design and Engineering. One end of the gauge implies an emphasis on Design; the other end of the gauge emphasizes Engineering. This gauge is based on historical evidence and interviews.



Organization D | Aerospace

Interviewee: Employee 1

Position: Senior Research Associate

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Human-computer Interaction	This term describes moments when a human will interact with a computer or technology.
NASA Solve [132]	This is the name of NASA's Design challenge website. NASA asks for public input when attempting to solve a space mission challenge.

The author conducted this interview before a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

Organization D is home to a Human Systems Integration Division. This division analyses human performance through modeling Human-Computer Interactions to improve the development of Aerospace systems. Employee 1 is a Designer and researcher and not a direct employee of Organization D. Employee 1 works fulltime on site at Organization D and their employment is under a non-profit organization that provides contracting positions. They work on Designing software for a government agency. They additionally work under a grant focused on future interfaces for astronaut crew medical support. In past years, their architecture team won a NASA challenge for a 3D printed Mars habitat. NASA often asks for input from the public in attempting to solve space mission challenges via "NASA Solve". [132] Since winning a challenge, Employee 1 has collaborated with various NASA centers.

Collaboration with other disciplines depends on the project being worked on. Often Engineers are not involved until after the schematic Step. Organization D's HCI (Human-Computer Interaction) team has a very strong foundation in user centered Design and its principles. Employee 1 has not experienced adversity in how software Engineers work with Designers. In their division, Designers, product developers and programmers are hired by the same people and work on the same team.

Barriers:

Employee 1's previous work in consultancy did show different relationships with Engineers. Sometimes Engineers did not see the value of having Designers around and it was felt that Employee 1 had to re-iterate and emphasize the value of Design Thinking and Design work in general because the implicit value was not recognized.

Methods and Techniques:

Within the employee's team at Organization D, Design Thinking, User Centered Design and its Methods are part of their day to day work. Chapter 4 (Section 1) further describes the Design Thinking Method. The work that Employee 1 supports tends to be different every project and they suggest that certain Methods do not apply well at different fidelities. At a higher fidelity a project has defined its project scope. Employee 1 suggests that Methods such as Design Thinking are better suited for early stages of ideation as described in Chapter 4 (Section 1). They use pen and paper in their workflow, as well as the Google suite of products along with Microsoft Word. [133, 134] They use Confluence and JIRA, 3D modeling software for architectural work, sticky notes for brainstorming. [135, 136] For habitat work they additionally use paper prototypes for the first few iterations. Chapter 4 (Section 2) further describes Prototyping.

This chart categorizes Methods, tools and areas where tools are used based on this interview:

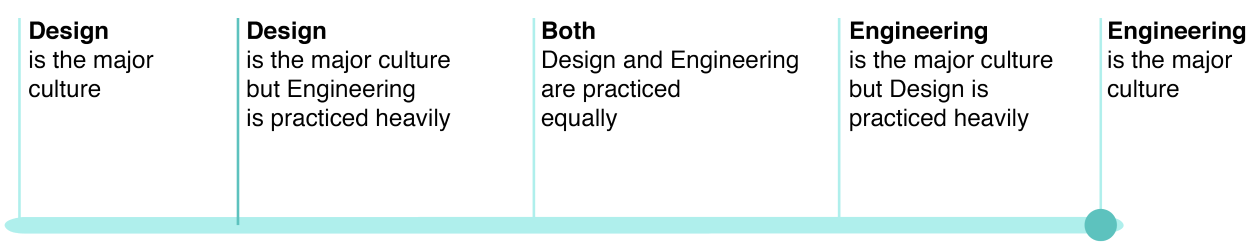
Methods	Tools	Techniques	Areas Used
Design Thinking	Pen, Pencil, Paper	Sketching	Habitat Design
Human Centered Design	3D Modeling Software	Drawing	Interfaces

	Confluence [135]	Prototyping	Software Development
	JIRA [136]		Brainstorms
	Google Suite [133]		
	Microsoft Office [134]		

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

This gauge captures the cultural value of an organization on the topics of Design and Engineering. One end of the gauge implies an emphasis on Design; the other end of the gauge emphasizes Engineering. This gauge is based on historical evidence and interviews.



Company E | Consumer Products

Interviewee: Employee 1, Employee 2, Employee 3

Position: Footwear Engineering | Color, Materials, Graphic Design | Women's Footwear

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Production	This Is a term for the process of creating a product.
Post Production	This is a term for product evaluation activities that occur after a product is complete.
Style	A way of dressing characterized by a particular time period or movement or place.

The author conducted this interview during a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

Employee 1 is a footwear Engineer with Company E. They support and develop processes for manufacturing and footwear development. Employee 1 begins with ideation and follows through to Production and Post Production such as quality control, etc. Within their role, they work within a set system for Designing footwear, however their team is comprised of people with a variety of skillsets. These skillsets include biomechanics, Engineering, Design and materials. Employee 1, as an Engineer, has the view that Designers solve problems in very different ways than Engineers or scientists. They see the benefit of Design as enhancing the Style of their product. Designers provide rapid Prototyping and tinkering to enhance the final product. Chapter 4 (Section 1) further describes Prototyping as used by Designers.

Teams within Company E are often Style driven. There may be a streetwear team, a sports team and an incubation team. These teams examine the future of fashion trends. Along with this “future forward” mindset, risk assessment is always an important piece of their process. Employee 1’s team is often able to provide insight into this area through technology research. Employee 1 states that Company E is very much a Design driven group. The visual portion of their product is all crafted by Designers. Sometimes, Employee 1 will have to tell a Designer that a product is not manufacturable because of either physical limitations or material incompatibility. They believe that a part of what makes their company advanced in footwear is the ability to leverage previous research done by their larger parent company. The close collaboration of individuals allows them to create products in a shorter amount of time. They also stress that multi-disciplinarity is important to their process.

Employee 2 works with the team that is the “creative brushstroke” that brings their seasons to life; the color, materials and graphic Design Team. Employee 2 states that their Designers perhaps work closest with Engineers. Teams across several disciplines can develop a variety of prototypes. A Designer may be looking at overall feel of a shoe, transition of stitches and line language, while an Engineer is with them looking at ease of entry, making sure fabric is not shrinking, and manufacturing risks. Designers and Engineers frequently collaborate, sometimes informally. This company has historically been supportive of the Design Discipline, not just because of their footwear Design, but also due to early campaign advertisements, the creative energy of which is still present today. Peers begin meetings with sharing their first or most beloved memory of their brand or product and they believe a sentimental affection for their brand to be a special thing. Backgrounds of Employee 2’s team members include industrial Design, chemical Engineering, fashion Design and even one MBA.

Employee 3 works in Women's Footwear. They frequently collaborate with both Engineers and Designers, often from the beginning of a project. There is often a set system for how they collaborate that everyone is aware of. They begin with goal setting, forming a team of experts and working to fine-tune as a collective unit. Employee 3 finds that their company and parent company are highly supportive of the Design Discipline in regards to imagining futures. Their process is innovative through their idea of Designing for a better world. Design is supported through trade shows, conferences and opportunities to explore other studios.

Methods and Techniques:

Employee 1 does not sketch personally, but others in their group do frequently. Most of their output is in a 2Dimensional space, using tools such as 3D modeling software such as Rhino and Adobe Illustrator. One of their Innovation groups "tinkers" and develops prototypes for future work. Prototyping is a large part of their process. They send sketches over email, and sometimes a Designer will sketch during a web meeting to communicate an idea.

Employee 2 does not mention utilizing any Methods described in this thesis, however their team frequently collages, sketches, paints and prototypes often using Adobe Illustrator and similar software. [137] Employee 2 likes to go directly to presentation format, because of the quick turnaround of ideas. Their company supports employees continuing with their education and understands the intricacies of Design. In one case, they supported Employee 1 taking a college course to develop a skillset in printmaking.

Employee 3 mentions that Design Methods are largely used at their parent company, where there are often dedicated roles for Design Thinking and Human Centered Design as described in Chapter 4 (Section 1). Techniques such as Sketching and Prototyping, further described in Chapter 4 (Section 2) are used often, with tools such as CAD modeling and Adobe Illustrator. [137] The majority of Designers utilize Adobe Illustrator for its accurate measurements in a 2-D space.

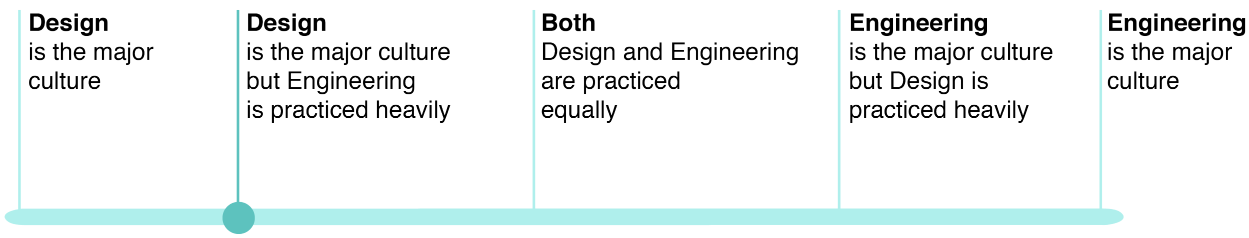
This chart categorizes Methods, tools and areas where tools are used based on this interview:

Methods	Tools	Techniques	Areas Used
Design Thinking	Pen, Pencil, Paper	Sketching	Footwear
Human Centered Design	3D Modeling Software	Drawing	Materials
	Adobe Illustrator [137]	Prototyping	Engineering
		Painting	Brainstorms
		Collaging	

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

Based on historical evidence and personal interviews, this gauge captures the emphasis a firm places on Design or Engineering, the middle being Neutral.



Company F | Aerospace

Interviewee: Employee 1

Position: System Architect

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Architecture	A plan and specifications for the implementation a spacecraft mission.
Proposal	This is a term for a document of a plan provided to stakeholders for funding.
Human Spacecraft Design	A plan for a spacecraft that is crewed by astronauts.

The author conducted this interview during a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

Employee 1 is a System Architect working predominantly on Human Spacecraft Design and Architectures in the early Design phase. Architecture in a space context is further defined at the end of Chapter 2 (Section 3) and Chapter 6. Employee 1's team starts early in the Design phase with a series of goals and assumptions that focusing on a conceptual Design, where they do analysis. They work in depth on this during the Proposal stage or pass it along to others. Employee 1's team helps other teams within the company solve technical problems. Company F has collaborative spaces that support interaction among team members and a large quantity of whiteboards for Sketching and ideating as defined in Chapter 4 (Section 1) and 2. Employee 1's team uses their whiteboards very frequently. Human Centered Designers are normally brought in during the beginning a project and involved in the early ideation process as described in Chapter 4 (Section 1). Design Disciplines that focus on translating scientific information for the public are brought in a few weeks into the development process and do not have decision making positions. These Designers depict the concept in a clear way using visual mediums such as illustration for stakeholders. There are conceptual Designers as described in Chapter 3 (Section 3) within the company and local Designers who are contracted to work with Design Teams. Within the past 14 years, Human Centered Design and graphic Design have been integral to the space technology development process at Company F.

Methods and Techniques:

Employee 1 recently has used Skype [138] because of its basic whiteboard capability. Confluence is another tool used by this company to support collaboration. Frequently, they 3D print for rapid Prototyping as described in Chapter 4 (Section 2).

This chart categorizes Methods, tools and areas where tools are used based on this interview:

Methods	Tools	Techniques	Areas Used
Human Centered Design	Pen, Pencil, Paper	Sketching	Engineering
	3D Modeling Software	Drawing	Brainstorms
	Skype [138]	Prototyping	
	Confluence [135]		
	Whiteboards		

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

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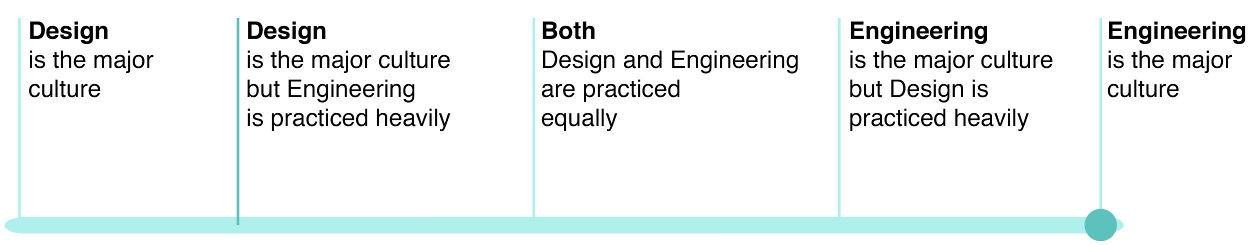


Organization G | Aerospace

Interviewee: Employee 1

Position: Technology Manager

Location: Washington, DC

The terms below are defined within the context of the organization. Key terms in the text are underlined.

Key Terms	
Innovation	A new idea in the form of a device or Method.
Startup	The development of a new business.
Trade Space Analysis	Identifying alternative solutions to fulfill a new requirement of a project.
Operations	This term describes technical activities that occur during day to day work.

The author conducted this interview during a shelter-in-place order due to the COVID-19 pandemic of 2020 and may have impacted results.

Overview and Opportunities:

Employee 1's role lies in overall Innovation, the intersection of culture, talent and environment that Organization G creates to support Creativity. Outreach and networking is important to what employees do to collaborate. Employee 1's group works to interact with academia, government and Startups for collaboration. They manage a research and Development portfolio. Engineers and Designers work together to develop ideas for technology projects, scope out options and define a Trade Space Analysis. Designers are relatively new within Company G, though they are becoming ingrained in Operations. Employee 1 believes that Designers are needed in the right place at the right time within projects. Employee 1 sees their company's process as Innovative in their adoption of elements of Design Thinking and other processes. Elements of Design Thinking are defined in Chapter 4 (Section 1). They see employees working across disciplines as important for their work, especially in the collaboration of different disciplines for Idea Generation.

Methods and Techniques:

Employee 1 sketches frequently, utilizes notepad software, Microsoft Word and has a preference for PowerPoint in order to constrain thoughts. Elements of Design Thinking are used within this company. [139, 134, 127] Serendipitous meetings are encouraged through dedicated spaces for collaboration. Sketching and Design Thinking are further described in Chapter 4 (Section 1) and 2 of this thesis.

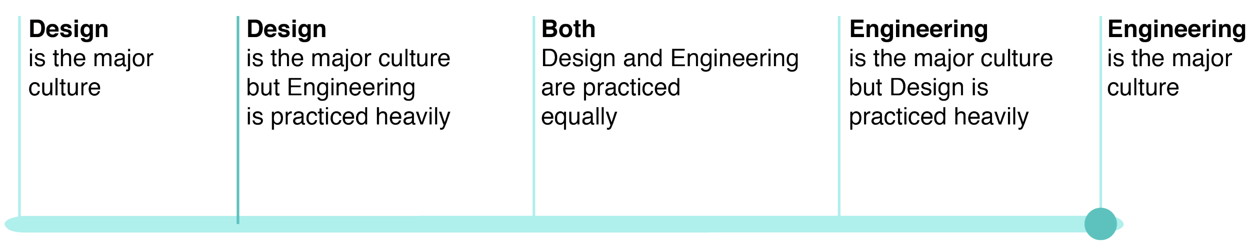
This chart categorizes Methods, tools and areas where tools are used based on this interview:

Methods	Tools	Techniques	Areas Used
Design Thinking	Pen, Pencil, Paper	Sketching	Engineering
	3D Modeling Software	Drawing	Brainstorms
	Powerpoint [127]	Prototyping	
	Microsoft Word [134]		
	Whiteboards		
	Notes [139]		

The table below describes how often exploratory Design Methods and Techniques are used.

Use of Exploratory Methods	**Never**	**Sometimes**	**Often**
Use of Exploratory Techniques	**Never**	**Sometimes**	**Often**

This gauge captures the cultural value of an organization on the topics of Design and Engineering. One end of the gauge implies an emphasis on Design; the other end of the gauge emphasizes Engineering. This gauge is based on historical evidence and interviews.



The tables below catalogue all Methods, Techniques, and tools used by the interviewees at their respective companies and organizations. Both software and hardware are listed together in the Tools section.

	Methods				Techniques						
	Design Thinking	*Human Centered Design*	*Science Fiction Thinking*	*Imagineering Process*	*Sketching*	*Prototyping*	*Storyboarding*	*Painting*	*Drawing*	*Photography*	*Collaging*
Company A	X			X	X	X	X		X		
Company B	X	X	X		X	X					
Organization C	X	X			X	X			X	X	
Organization D	X	X			X	X			X		
Company E	X	X			X	X		X	X		X
Company F		X			X	X			X		
Company G	X										

	Tools																		
	Microsoft Word	*Microsoft PowerPoint*	*Microsoft Skype*	*Google Suite*	*Notes*	*Confluence*	*JIRA*	*Cinema 4D*	*AutoCAD*	*Adobe Illustrator*	*Adobe Photoshop*	*Adobe AfterEffects*	*Rhino*	*Matlab*	*Revit*	*Alias*	*Wacom Tablet*	*Pen, Pencil and Paper*	*Unspecified 3D Modeling Software*
Company A		X				X			X		X		X	X	X	X		X	
Company B		X							X									X	
Organization C								X		X	X	X					X	X	
Organization D	X	X	X	X		X	X		X									X	X
Company E										X								X	X
Company F			X			X												X	X
Company G	X	X			X													X	X

Chapter 6 | Mission Concept Development

NASA, the United States' National Aeronautics and Space Administration, is the civil government agency responsible for science and technology related to space. It was developed to oversee and guide aeronautics research. NASA's vision is "To discover and expand knowledge for the benefit of humanity." [140] Their missions of scientific discovery include Earth, the solar system and the cosmos. NASA expands knowledge in these areas through exploratory missions of the solar system via humans, robotic probes and spacecraft. The four strategic themes at the foundation of NASA's plan for space exploration include: Discover, Explore, Develop and Enable. [140] The author has listed direct quotes describing these themes from the NASA Strategic Plan (2018) below.

NASA Strategic Plan (2018), Strategic Themes

1. **Discover |** Expand human knowledge through scientific discoveries.
    a. Understand the Sun, Earth Solar System and Universe.
    b. Understand responses of physical and biological systems to spaceflight.
2. **Explore |** Extend human presence deeper into space and to the moon for sustainable long-term exploration and utilization.
    a. Lay the foundation for America to maintain a constant human presence in low Earth orbit enabled by a commercial market.
    b. Conduct Exploration in deep space, including to the surface of the moon.
3. **Develop |** Address national challenges and catalyze economic growth.
    a. Develop and transfer revolutionary technologies to enable exploration capabilities for NASA and the Nation.
    b. Transform aviation through revolutionary technology research, development and transfer.
    c. Inspire and engage the public in aeronautics, space and science.

4. **Enable |** optimize capabilities and Operations.
    a. Engage in partnership strategies.
    b. Enable space across access and services.
    c. Assure safety and mission success.
    d. Manage human capital.
    e. Ensure enterprise protection.
    f. Sustain infrastructure capabilities and Operations.

This agency also supports a number of national priorities whose categories can be described as:

1. "Fostering new discoveries and expanding human knowledge." [140]
2. "Global Engagement and Diplomacy." [140]
3. "Interactions with the Nation's Security and Industrial Base Posture." [140]
4. "Economic Development and Growth." [140]
5. "Addressing National Challenges." [140]
6. "Leadership and Inspiration." [140]

NASA follows a specific process for developing Architectures for its science missions. Space mission Architectures are Designs and plans implementation and operation of spacecraft. This chapter discusses the current Flight Mission Project Lifecycle through the lens of a Designer, taking reference from materials on the topic, such as the "NASA systems Engineering handbook" and "Space Mission Engineering: The New SMAD". [141, 11] The author additionally uses evidence from interviews and dedicated NASA Design Teams. Areas where this discipline may be supportive are detailed based on literature in Chapter 2 and 4 of this thesis. A Method and/or Technique has shown to be supportive if it aligns with and supports each phase's requirements to meet the next Lifecycle Phase.

NASA has four main mission directorates that support their goals: Aeronautics Research, Human Exploration and Operations, Space Technology and Science. This thesis focuses on space mission development within the Science Mission Directorate, which “seeks to understand the origins, evolution, and destiny of the universe and to understand the phenomena that shape it.” [142]

NASA is informed by multiple Decadal Surveys in its process for defining space missions for science. Science Divisions within NASA collaborate with the National Academy of Science to perform a Decadal survey for their field. These fields include Planetary Science, Earth science, Astronomy & Astrophysics, and Heliophysics. [143] They provide suggestions describing the science objectives that should be prioritized in the next ten years. While NASA is not bound to execute everything in the Decadal Surveys, NASA leadership does consider the recommendations when selecting science missions to propose for funding in the NASA budgeting process.[143] NASA missions can be either competed or assigned by NASA Headquarters to be carried out by a NASA Field Center or Research Institution. The term “competed” means various parties, often NASA Field Centers and other institutions propose detailed concepts to be selected as a mission by a committee of reviewers. This process can take many months, if not years and involves a series of reviews and site visits from the reviewers. Assigned Missions are often larger Flagship missions, led by NASA Field Centers and assigned to a center by either NASA Headquarters or Congress. [144]

At the Jet Propulsion Laboratory, Designers can be observed in a few stages of the competed and Assigned Missions process. In the Pre-Phase A area, Proposal Stage, and much later in the Site Visit portion of the competed mission process.

- Pre-Phase A: Visual Communication, often Sketching, Drawing and key graphics development.
- Proposal Stage: Storytelling and Key Graphics development.

- Site Visit: Key Graphic development, model prototype fabrication, physical space organization and visitor flow-through.

Additionally, there are two mission models for planning missions within the NASA Science Mission Directorate: Strategic and PI-Led. Strategic missions can be large or small. They are meant to fulfill gaps of knowledge. Instruments can also be competed, however, NASA centers lead the entire space mission. PI-led missions are solicited from the science community for whole missions, not only Instruments as seen in strategic missions. The PI-led mission teams are comprised of individuals from universities, government laboratories and small businesses to develop and operate the mission. NASA clearly states this approach “encourages Creativity, and provides opportunities for new entrants into scientific space mission development.” [145] This statement echoes the importance of multi-disciplinarity for Innovation as observed in employee interviews in Chapter 6. [145]

Additionally, while missions have varying levels of criticality, NASA has provided guidelines to govern the different levels. These levels include: Classes A, B, C and D as well as specific categories: 1, 2 and 3. Classes A, B, C and D are meant to assess risk. Class A is the lowest risk, Class B is Low risk, Class C is Moderate Risk, and Class D is highest risk. [146]

Large Category 1 Missions are considered highest priority. Cassini and Galileo are considered Category 1. [147, 148] Medium sized missions are Category 2. This category tends to have a unique objective and can include a variety of Instruments for their more focused project. [149]

6.1 NASA Flight Mission Project Lifecycle

NASA competed and Assigned Missions follow this strict series of reviews and checkpoints on their way to becoming a mission. The light grey portions are space Mission Concept Development, identifying how the program or project supports the Agency's strategic goals. Systems Engineers develop and allocate program requirements to initial projects. The dark grey portions indicate the steps taken after a mission concept has been approved (program start).

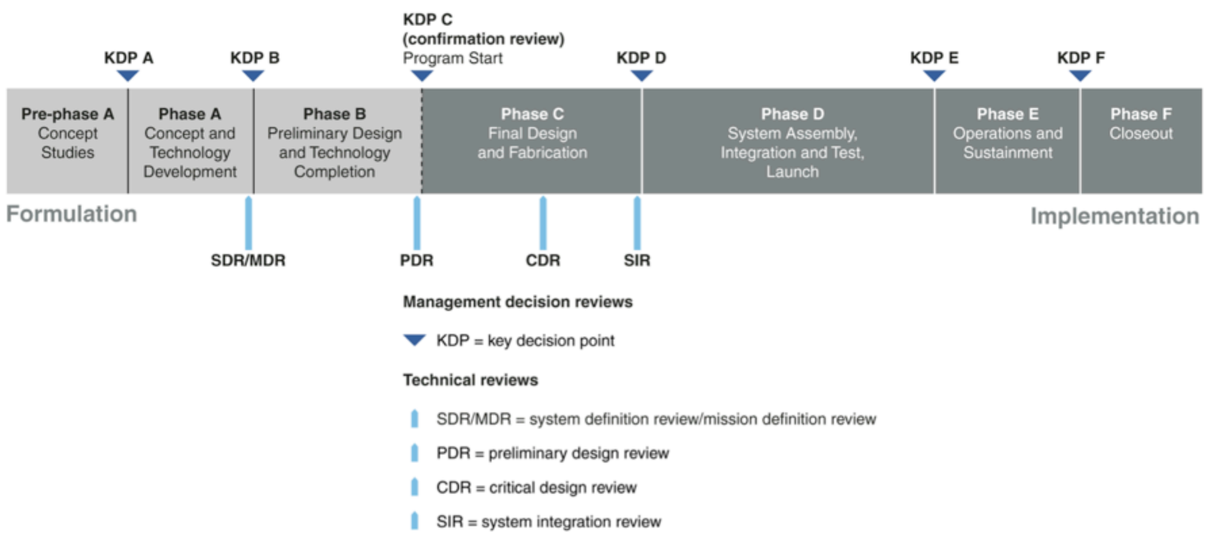


Fig.9 NASA Flight Mission Lifecycle Credit: NASA/GAO

A crucial aspect of the Mission Architecture process is the management of the project lifecycle. Separated by Key Decision Points (KDP)s, the phases are distinguished in such a manner that each portion can be reviewed for readiness prior to continuing into the next phase. Key Decision Points are events during which the decision authority determines that the project is sufficiently ready for the next steps. [150]

The process begins with the recognition of a need or an objective. Tasks performed by Systems Engineering such as optimization and analysis are completed in the early stages. [11] A key creative step in Systems Engineering is referred to as synthesis, which involves transition from a functional architecture (what a mission has to do) to a physical

Architecture (what a mission looks like). This Chapter will describe the various phases below and note areas where the Design practice is currently present.

6.2 Program Formulation

Pre-Phase A | Concept Studies

The first stage of the mission lifecycle is Pre-Phase A, also known as Formulation. Concept Studies are conducted during this stage. The purpose of this section is to provide a multitude of mission options and analyze whether they fall within scope and cost, budget and scheduling. Through analyzing various concepts, a team can identify promising ideas for Space Mission Architecture. Architectures are Designs and plans implementation and operation of spacecraft. Systems Engineers are extremely involved in the concept development process. [11]

Various NASA centers have formed specific divisions that support Concept Studies, such as Ames Mission Design Division and the A-team housed within the Innovation Foundry at the Jet Propulsion Laboratory. [55, 8] Notably, the Jet Propulsion Laboratory has developed a number of improvements in the lifecycle that support Pre-phase A. [151] They Include:

- "Detailed Life-Cycle templates map out sub-phases, gates, and reviews for competed and Assigned Missions." [151]
- "Concept Maturity Levels: consistent approach measures maturity of mission and instrument concepts." [151]
- "Cost Risk Subfactors: algorithm estimates appropriate cost reserve posture very early, based on influence coefficients extracted from recent flight projects." [151]

- “Cost and Schedule Profile Rules of Thumb: guidelines establish schedule and cost profiles as a function of mission class, based on historical data.” [151]
- “Formulation Support Team: institutional experts join all pre-projects to assure tailored support.” [151]
- “Pre-Project Principles & Practices: detailed guidelines clarify concept development expectations in each life-cycle sub-phase.” [151]
- “Frontline web portal: provides on-line access to current information, templates, and standards for study teams, Proposal teams, and pre-projects.” [151]
- “Mission Development Workshop: week-long class provides in-depth discussion of Techniques for concept development, competition and Proposal preparation, cost estimating, and early Formulation planning” [151]
- “Senior management attention: new position of JPL Associate Director for Project Formulation and Strategy coordinates Lab-wide policy through a new Office of Strategic Planning and Project Formulation.” [151]

All of these improvements provide stability and quality control for a normally ambiguous time in a mission’s lifecycle. JPL has additionally supported including non-Engineering Disciplines, such as Designers, in this phase going so far as to support changes within the rigidity of government processes to include them. It is recognized that Design Thinking and Storytelling are important parts of the Innovation Foundry process.[2] It is unknown whether other NASA centers support the Design Discipline in this manner within Pre-phase A. As noted in Chapter 4 of this thesis, visual communication Techniques, such as Sketching and Storyboarding differ within specific Design Disciplines and an understanding of the specific Techniques at their disposal is needed for optimal utility. It may be implied that the Storyboarding Technique used primarily by Concept Designers, for example, may be able to support the scheduling or ConOps (Concept of Operations) process, providing a powerful communication tool. ConOps has been described as a document outlining leadership’s expected process for implementing a project. Clarity of information is important for ConOps. This document captures the architecture of a system. [152]

In an MIT course, *Fundamentals of Systems Engineering*, Designer Sheng-Hung Lee utilized Design Techniques as described in Chapter 4 (Section 2) of this thesis to communicate the ConOps in addition to the traditional written document. [153] While graphic visuals are used to communicate ConOps, they may be created by Engineers that have been shown in Chapter 4 (Section 2) to not have foundational studies in Design Techniques. Sheng-Hung Lee applied the Design Thinking Methodology and his Sketching and Drawing Techniques as a Designer to the systems Engineering Method "OPM" (Object-Process Methodology). OPM is a systems Engineering Method of capturing knowledge based on "two main components: elements/process and process/feature". [154, 153] Lee envisions a "creative approach to solving systematic challenges in the future." [153] The Visualization achieved through the Sketching Technique crosses discipline specific languages and is clear in its communication. The example below shares elements of the Story boarding Technique described in Chapter 4 (Section 2) of this thesis. The visual illustrates an event in chronological order.

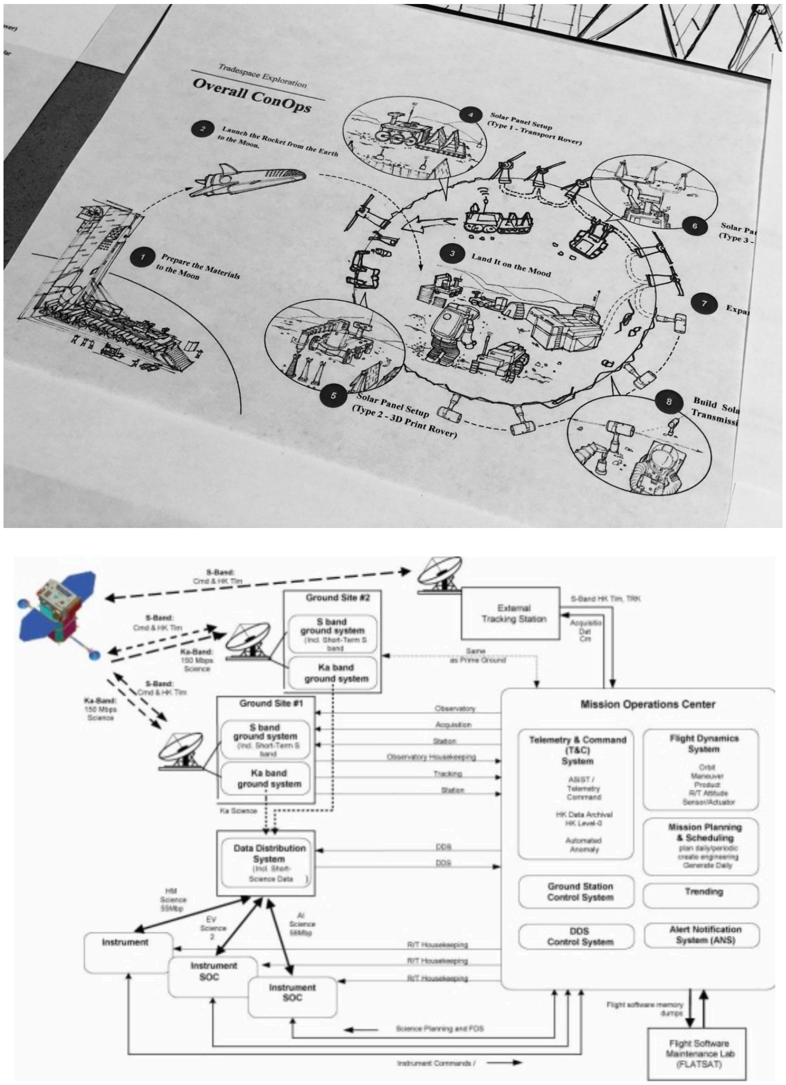


Fig. 10 Top: ConOps Design by Sheng-Hung Lee. Bottom: ConOps from the NASA Systems Engineering Handbook, 2007

While the top Design in figure 10 may be seen as a finished piece, these sketches can be completed during meetings of Design Teams. Graphics similar to these are usually completed much later in the process, often as a key graphic for a Proposal and not as early in the process. Perhaps a Designer's competence in the Sketching and Storyboarding Technique specifically may be supportive to the systems Engineering Discipline in Pre-Phase A.

The goals of Pre-Phase A include providing a multitude of options and analyze whether they fall within scope and cost, budget and scheduling. The following Methods and Techniques may be of support of Pre-Phase A's goals in the areas of Idea Generation, analyzing a multitude of options, and identifying promising solutions. I have defined the style of Sketching that may be most beneficial based on interviews and research and will do so for other phases. The definitions of Sketching styles can be seen in Chapter 4 (Section 2).

Methods	Techniques
Design Thinking	Sketching- Entertainment, Industrial
Science Fiction Thinking	Prototyping
	Storyboarding

Phase A | Concept and Technology Development

The aspiration of Phase A is to advance a proposed system architecture developed in Pre-Phase A that is plausible and meets the requirements of the objective. Systems Engineers assign responsibilities for technology development and resources during this stage. Leaders provide documents to their team outlining expectations for advancement and maturity of the program requirements. Systems Engineers are also involved in development of architecture and distribution of requirements to the various elements. [11]

NASA Headquarters is the main actor in allocating budget and technical responsibilities to NASA Field Centers and research institutions to implement scientific missions. A team selected by NASA Headquarters reviews a proposed mission concept developed in Pre-Phase A. The reviews evaluate the project objectives, requirements and constraints to justify whether the concept has merit for NASA funding. Systems architecture is formalized and goals are cemented along with depth into a variety of system options.

Architectures are Designs and plans implementation and operation of spacecraft. Goals can mean reaching of science objectives and budget targets. [11] The conceptual Design is meant to become more detailed in its Engineering Design than in Pre-Phase A. A system Engineering management plan is also developed as a baseline. System Engineers assign functions to humans, hardware and software, while SME's (Subject Matter Experts) are brought in during this stage to assess the cost effectiveness of the Designs. A system-level cost-effectiveness model is developed to determine lifecycle cost. [11]

The goal of this stage is to define a concept and advance a proposed system architecture. Because cost becomes more significant during this stage, the Science Fiction Method and its use of Morphological analysis may support the team in reviews of objectives, requirements and constraints. [11] Techniques such as Sketching and Storyboarding can support Idea Generation, visual communication and defining concepts during group meetings to reach consensus. Additionally, Prototyping can be started early at a low fidelity as can be seen in most Design Methods in Chapter 4 sections 1 and 2. They can be Methods and Techniques below may support this phase:

Methods	Techniques
Science Fiction Thinking	Sketching- Entertainment, Industrial
	Storyboarding
	Prototyping

Phase B | Preliminary Design and Technology Completion

Phase B of the process is meant to complete critical tasks such as Engineering Prototyping, software assessments, heritage hardware and risk-mitigation. At this stage, the project should establish and demonstrate consistency in schedule, cost, technical and planning guidelines. During this phase, the team confirms that the mission concept is feasible and that there are no major risks that might make it impossible to complete the mission. Objectives specified in the ConOps should be used to validate Design choices. This phase is a collection of baselines that cover both business and technical portions of the system. Any changes at this stage should be measured against baselines. [11]

A sequence of PDRs (Preliminary Design Reviews) are the last stage in this process and must be satisfied through appropriate clarification of both overall systems level Design and smaller, lower level systems such as scientific Instruments. Preliminary Design Reviews are the process through which a team can demonstrate that a prospective Design meets system requirements while keeping in line with scheduling and cost constraints. [11]

Opportunities for inclusion of Design Methods and Techniques include Prototyping, and software assessment clarification through visual aids. Additionally, the Sketching Technique can support clarification of the ConOps and visual communication amongst team members during meetings. Visual communication can also include clarification of information for PDRs (Preliminary Design Reviews). Changes to the collection of baseline documents can be supported by the Science Fiction Thinking Method's morphological analysis charts and are further described in Chapter 4 (Section 1). Supportive Design Methods and Techniques are placed in the chart below:

Methods	Techniques
Science Fiction Thinking	Sketching- Entertainment, Industrial
	Storyboarding
	Prototyping

6.3 Implementation

Phase C | Final Design and Fabrication

Detailed Designs of the system should be complete at this stage and fabrication should be realized, including coding. Engineers in this stage fabricate hardware, breadboards, and code that are meant for integration. Integration within this context means to combine subsystems and their interactions into the whole system of a spacecraft. [155] While items are now finalized, trade studies continue and are meant to certify the system against goals, objectives and ConOps. Engineering prototypes are developed to review and certify that Designs will function appropriately. This Chapter focuses on Science Missions, however in this case, if a project involves human subjects, they are included in this stage to test and evaluate the Design. This Prototyping stage is prime for Human Centered Designers, Interaction Designers UX and UI Designers whose skillsets align with Human Factors. The Boeing Company, for example, has a dedicated User-centered Design Team, something seen in few NASA centers. [156]

Results from these analysis results are folded into the Designs and Systems Engineers define manufacturing processes. The Systems Engineer should be able to answer questions and work to resolve issues during fabrication. Systems Engineers are a part of this process to ensure systems continue to work together. Parameters such as schedules and budgets are tracked to begin to capture metrics that may be undesirable.

At this stage they can be recognized early. This stage contains multiple CDRs for system level and including lower level Designs. Before fabrication of hardware, a CDR is held. This phase continues into Phase D with a successful SIR (System Integration Review). A SIR is a review that determines if components and subsystems are ready for integration into a system. It also makes sure integration is on schedule and enough support personnel are available. [11]

Phase C's goals are to fabricate hardware, breadboards, software coding and are meant for integration. While this is happening, trade studies continue and prototypes continue to be developed. The Science Fiction Thinking Method's morphological charts and the Sketching Technique can contribute to visual communication during team meetings about trade studies. Storyboarding can additionally be utilized during team meetings in the event that an operation needs to be clarified. Low fidelity Prototyping as described in Chapter 4 (Section 2) can be used during hardware fabrication. The Design Methods and Techniques discussed in this interview are listed below.

Methods	**Techniques**
Science Fiction Thinking	Sketching- Industrial
	Storyboarding
	Prototyping

Phase D | System Assembly, Integration and Test, Launch

This phase includes assembly and integration and also includes verification and validity of the system in preparation for the Flight Readiness Review (FRR). Assembly means the process of combining the final hardware together. [11] Verification within this context is defined as the testing of hardware under simulated environmental conditions. [11] Flight Readiness Review (FRR) is a review that examines the tests and analysis to ensure flight readiness. [11] At this stage there are rehearsals and training of operating personnel and crew members along with testing of the flight system for the expected environment. Systems Engineers are on hand to resolve issues, provide advice and to asses results. They give input to decision makers when a choice is made whether to move forward into the next phase. Any changes at this point can result in a high cost. At this point, Designs are finalized and the final system is capable of reaching its objectives. [11]

The system has been finalized at this stage, however Designers play a role in Communications. Graphics and Concept Designers work with scientists on highlighting the objective of the mission to the public. Phase D goals include tests and analysis, results of which can be visualized through Design Techniques when clarifying detailed information for stakeholders. Teams during this stage also rehearse and train for spacecraft Operations. Storyboarding proves to be beneficial for describing events and occurrences in chronological order. The Human Centered Design Method, through its focus on individuals, may be beneficial for Systems Engineers when developing Operations processes. These Methods and Techniques are described in Chapter 4 (Section 2).

Methods	Techniques
Human Centered Design	Sketching- Industrial, Entertainment
	Storyboarding

Phase E | Operations and Sustainment

During Phase E, the mission is implemented for the objective it was Designed for and sustained for that objective. Systems Engineers often play a role in this phase because of their prior experience with complex systems. Systems with complex needs and adjustments may need updating beyond the duties of an operator. As an example, there may be information that needs to be sent to the satellite via radio link. Any large changes to the objectives, or "needs" would require restarting of the project lifecycle. Systems Engineers additionally determine faulty behavior called "inflight anomalies" when they occur. At this late stage, NASA Field Centers develop operating software with the support of an interface or Human Centered Designer.

In regard to software and interfaces during operation, a recent example from 2018 describes the need for Designers involved in Software Development. On the morning of January 13th, 2018, a false ballistic missile alert was sent to Hawaii via television, radio and cellphone. This alert told residents to seek shelter, and that it was "not a drill." Governor David Ige later apologized for the miscommunication and the House of Representatives began an investigation, which ended with the resignation of the state's emergency management administrator. The administrator of the Hawaii Emergency Management Agency has stated the alert was inadvertently triggered by an employee. Following the event, leading Design journalists at Core77 dissected the User Interface. [157]

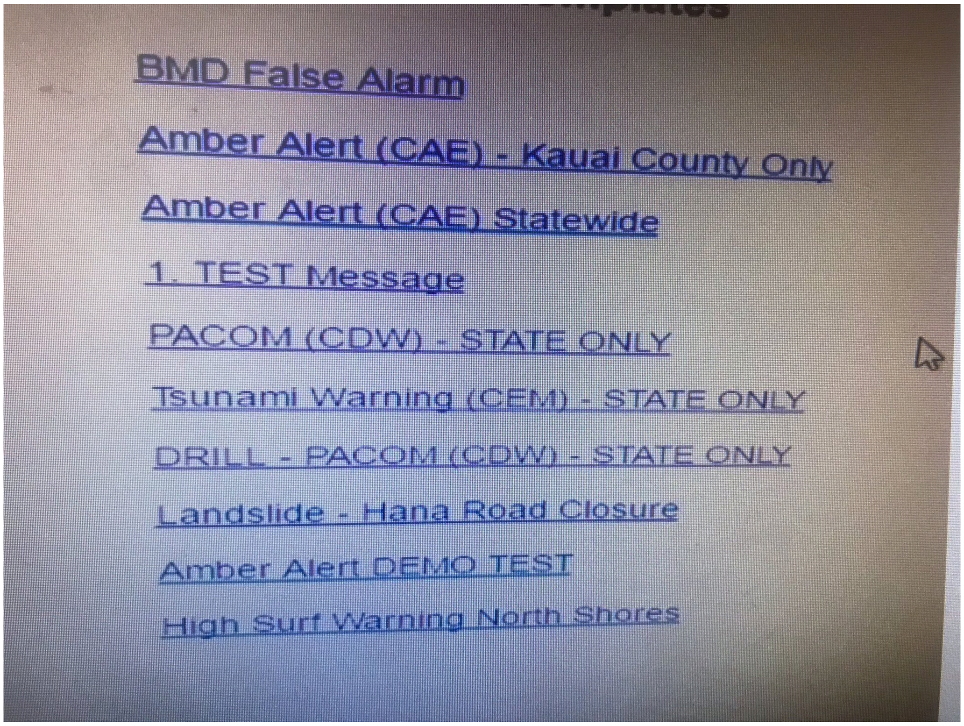


Fig. 10 An image of the missile alert system. The missile launch alert is labeled as "PACOM (CDW)- STATE ONLY". Credit: Honolulu Civil Beat

An Article by The Daily News, states, "The employee [responsible], who has not been identified, selected a missile launch warning from a drop-down menu instead of selecting an internal test alert that kicks off a new shift, [Hawaii Emergency Management Agency] spokesman Richard Rapoza said. Not knowing he had selected the wrong option, he clicked "yes" when the computer prompt asked if he would like to continue. The worker realized the epic proportions of his error after receiving the same frightening missile alert on his own phone." [157]

To an Interface Designer, User Centered Designer or Human Centered Designer "human error" is often evidence of larger, systematic problems. Some of the time, it's the case that errors that seem to be caused by humans are actually the fault of systems that are not designed with human interaction in mind.

During Phase E science is obtained that needs to be communicated to the public. Designers use Techniques such as Sketching to take the complex data and make it digestible to the public. It may evolve into graphic Visualizations, video, illustrations and sometimes concept Artwork. Human Centered Designers may be able to assist Engineers in development of software that is intended for use by humans. Some programs within this stage have multiple flights or Operations. They may need configuration changes and may have new mission objectives each time. [11] The Design Thinking Method may assist Systems Engineers in organizing ideas and concepts through visual means. This Method may provide an additional way of documenting information. Storyboarding may be beneficial when documenting events and occurrences in chronological order. The following Methods and Techniques support Phase E:

Methods	Techniques
Design Thinking	Sketching- Industrial, Entertainment
Human Centered Design	Storyboarding

Phase F | Closeout

Phase F may occur many years after the launch and operation for a mission begins, though the plan for Phase F is addressed beginning in Pre-Phase A as part of the overall mission architecture. This step indicated the mission has completed its objectives and plans for a mission's decommissioning and disposal. The team, in previous phases, has established plans for decommissioning of their project. For a long term space mission, decommissioning may come unannounced in the form of hardware or software failures.

NASA additionally has requirements for reducing orbital debris. The "NASA Procedural Requirements for Limiting Orbital Debris", has requirements for the decommissioning of

Earth focused spacecraft at the end of their lifecycle. Often, Low Earth Orbit Satellites are de-orbited and can burn upon re-entry, however larger satellites are intended to de-orbit into a targeted region of the ocean. Geostationary satellites, the farthest from Earth, cannot be practically de-orbited, and so are instead pushed into a higher orbit. In a project's earlier phases, a closeout plan has been developed, along with a series of options for when and how it will happen. [11]

Designers can be seen in this stage gathering final data from scientists for organization into graphical elements for research papers based on findings. One example of Communications can be seen in the Cassini mission's grand finale at Saturn. It won an Emmy for its production of interactive mission coverage, producing high quality web, news, social media and television products. The Sketching and Storyboarding Technique as described in Chapter 4 (Section 2) enable the production of these graphical assets. [158] When developing concepts for graphical assets, Design Methods such as Design Thinking and the Imagineering Process can be used to support Idea Generation and Storytelling as seen in Chapter 4 (Section 1).

Methods	Techniques
Design Thinking	Sketching- Entertainment, Industrial
Imagineering Process	Storyboarding
	Prototyping

The Flight Project Lifecycle below catalogues the Methods and Techniques defined in Chapter 4 and their relevance to each phase of the Flight Mission. Information is organized based on evidence from interviews and goals for each phase discussed in Chapter 6. Techniques have been shown to be used more often than any specific Method. Distinctions between styles of Sketching are indicated.

Formulation — Implementation

KDP A — KDP B / SDR/MDR — PDR / KDP C (confirmation review) Program Start — CDR — SIR / KDP D — KDP E — KDP F

Pre-Phase A Concept Studies	**Phase A** Concept and Technology Development	**Phase B** Preliminary Design and Technology Completion	**Phase C** Final Design and Fabrication	**Phase D** System Assembly Integration and Test, Launch	**Phase E** Operations and Sustainment	**Phase F** Closeout
Design Thinking Science Fiction Thinking	Science Fiction Thinking	Science Fiction Thinking	Science Fiction Thinking	Design Thinking	Design Thinking Human Centered Design	Design Thinking Imagineering Process
Sketching Entertainment Industrial Protoyping Storyboarding	Sketching Entertainment Industrial Protoyping Storyboarding	Sketching Entertainment Industrial Protoyping Storyboarding	Sketching Industrial Protoyping Storyboarding	Sketching Industrial Protoyping Storyboarding	Sketching Entertainment Industrial Protoyping Storyboarding	Sketching Entertainment Industrial Protoyping Storyboarding

KDP = key decision point

Technical Reviews

SDR/MDR = system definition review
mission definition review

PDR = prelimenary design review

CDR = critical design review

SIR = system integration review

6.4 Supportive Design Areas

It has been seen from interviews conducted for this thesis that Design Methods and Techniques have been found to be beneficial to professionals working in the Aerospace sector. Design Techniques can be of support in a variety of phases, particularly the Formulation stage: Pre-Phase A, Phase A and B. The Formulation stages may be a place where the Design practice can be of most benefit because of the iterative nature of the Design practice. The later phases call for finalization of specifications and have significantly less room for iteration, however communicating visually in later stages may also be beneficial in support of systems Engineers, for example, continuing trade studies, for design of software and the usual support of idea and data organization.

Concept Maturity Levels (CMLs) is a categorization system developed at the Jet Propulsion laboratory through which a space mission concept can be communicated and scoped. These levels are based on the frequently used Technology Readiness Levels. Technology Readiness Levels are a measurement system through which the maturity of a technology can be compared to other technologies of the same kind. [159] CMLs benefit mission concepts through the series of clear steps and assessments that allow a mission to mature from level 1, the “Cocktail Napkin Sketch stage”, through Level 8, “Project Base Line”. Especially important is its ability to measure the work conducted during Pre-Phase A. Previously, there was no unified Method through which to measure when in the pre-project’s lifecycle a trade-space exploration may be most beneficial to determine science relevance and cost-effectiveness, examine different concepts that were similar in their levels of work and the amount of effort required to reach the next level of maturity. [160] Chapter 6, (Section 2) of this thesis discusses the pre-Formulation process on a larger scale.

There are three areas of importance documented in the early CML six-dimensional hexagon (science, Engineering, Implementation, cost, communications and strategy) that may benefit from the categorization of Exploratory Methods and Techniques. These three areas are: Storytelling, capturing Achievable Futures and Idea Generation. [8] It is recognized by the JPL Innovation Foundry that three areas in Pre-Phase A could use support. [8] The purpose of this chapter is to describe the Methods and Techniques that may support these areas based on interviews and historical references.

Storytelling

Early CML levels identify Storytelling as a necessary component of communicating and extracting their science objective. Storytelling in this case means communicating an engaging mission concept and science objective within the team and outside of it. The JPL Innovation Foundry, which utilizes CMLs has recognized a difficulty among people from the Engineering Disciplines with expressing narrative, through both Storytelling and Drawing Technique. [8] The Disney Imagineering Process holds Storytelling at its core and centers its entire process around enhancing Story. [8] It is the Methodology through which Disney develops its theme park Attractions. There are similarities already with the Pre-phase A process and the Imagineering process, however a large difference can be seen in the heavy use of Design Techniques such as Sketching that amplify visual communication within Disney. Storyboarding, Sketching and Model Making/Prototyping may be a powerful tool during this iterative stage, considering that it has supported Disney in its Storytelling process during their Engineering concept ideation.

The author's prior research on Feature Film Techniques for space mission planning supports the entertainment skillset's impact on space mission planning. The author utilized a Technique from Feature Film, Matte Painting, to visualize the terrain of a comet for the Rosetta mission before any photographic images were taken. Matte Painting is the Design Technique of representing a landscape through Painting in the Feature Film industry. [161]

In June 2013, the Rosetta team was well underway planning its approach to target comet 67P. The mission Manager of the U.S. portion of the Rosetta team, Art Chmielewski and scientists found inaccuracies in previous Concept Designs of the Rosetta Mission as new data continued to be collected. Accuracy in Concept Design was important in this mission's case because at the time, there was no photographic imagery of 67P's terrain. [161]

A Concept Designer (the author) specializing in Entertainment Design was hired from the local college, Art Center College of Design, to depict the comet with new data that had been collected. Skillsets of the illustrator include: Storyboarding, Concept Design, and Matte Painting for Feature Film. [161]

As the work of Maria Yang (MIT) shows, Sketching Technique varies among Designers. She analyses the role of a Designer's Sketching ability and the possible link between Sketching skill and Engineering Design performance. [9] Chapter 4 (Section 2) describes Techniques for visual communication that may be more beneficial to the Aerospace Industry than any particular Methods discussed in Chapter 4 (Section 1). JPL has previously invited Pixar Storytellers to provide guidance and advice on the way mission stories are told using Pixar's Storytelling Method.

Techniques:

- Storyboarding: Developed specifically for Storytelling, can be created in real time with moving pieces. Entertainment Designers/Concept Artists frequently use this skillset. (Chapter 4.2)

- Sketching: The Sketching ability, when involved in concept development and ideation, has been seen to improve Design outcome. [45, 66, 68] (Chapter 4.2) It also visually communicates Story elements.

Methods:

- Science Fiction Method: For sparking Imagination amongst team members.

Idea Generation

Idea Generation is supported by Stanford D. School's Design Thinking Methodology. Idea Generation within space Mission Concept Development involves experts generating various ideas for a space mission. The Design Thinking process is described by the Interaction Design Foundation as "a Design Methodology that provides a solution-based approach to solving problems. Design Thinking is extremely useful in tackling complex problems that are ill-defined or unknown, by understanding the human needs involved, by re-framing the problem in human-centric ways, by creating many ideas in brainstorming sessions, and by adopting a hands-on approach in Prototyping and testing." [77] Design Thinking and Human Centered Design support Idea Generation through both analyzation and categorization. Human Centered Design is described by IDEO.org as a process that begins with people being Designed for, and ending with solutions tailor made to suit their needs. It highlights building empathy for those being Designed for. Consisting of three phases, Inspiration, Ideation and Implementation. [78] These Methods are further described in Chapter 4. An element that closely relates to Science Fiction Thinking, "The Thing From The Future" also supports Idea Generation. The following section, "Achievable Futures," describes this element further.

Techniques:

- Sketching: The Sketching ability, when involved in concept development and ideation, has been seen to improve Design outcome.
  (Chapter 4.2)
- Prototyping: A low fidelity model of a product used to test the object, obtain user feedback or communicate a concept. (Chapter 4.2)

Methods:

- Design Thinking (Chapter 4.1)
- Human Centered Design (Chapter 4.1)

Achievable Futures

Also important during Pre-Phase A is understanding science return, mission scenarios and payload options. Science teams sometimes struggle to ideate an achievable scope within cost constraints.[11] Science Fiction Thinking, developed by Innovation consultancy Perception Studios, has developed their Method to play out potential futures and outcomes through extrapolation. Perception Studios defines Science Fiction Thinking in relation to Design Thinking, "Whereas Design Thinking is searching for alternative solutions, Science Fiction Thinking is searching for alternative futures." [95] They outline their Method in four sensory stages, "Perceive + Define, Imagine + Envision, Build + Create, Inspire + Believe. [80] This Method can be further reviewed in Chapter 4. It is mentioned that an MIT course, "Science Fiction- Inspired Envisioneering and Futurecrafting," or "Science Fiction Fabrication," utilizes proven technology extrapolation Methods, such as the "Zwicky Box" and the "The Thing from the Future" to allow students to fabricate and reverse Engineer Artifacts seen as science fiction from Feature Film. [100] From the course, ideas such as Spiderman's "Spidey-Sense" come to life through working prototypes. [97, 101]

The Zwicky Box was developed as a morphological analysis model by Fritz Zwicky for non-quantifiable problems where the usual Methods of modeling and simulation don't model well, if at all. It can be highly visual and uses a grid box system to eliminate and reduce unviable solutions and compare them to others through variables such as cost, power and manufacturing. It has since been applied to future studies and the field of policy analysis. [100]

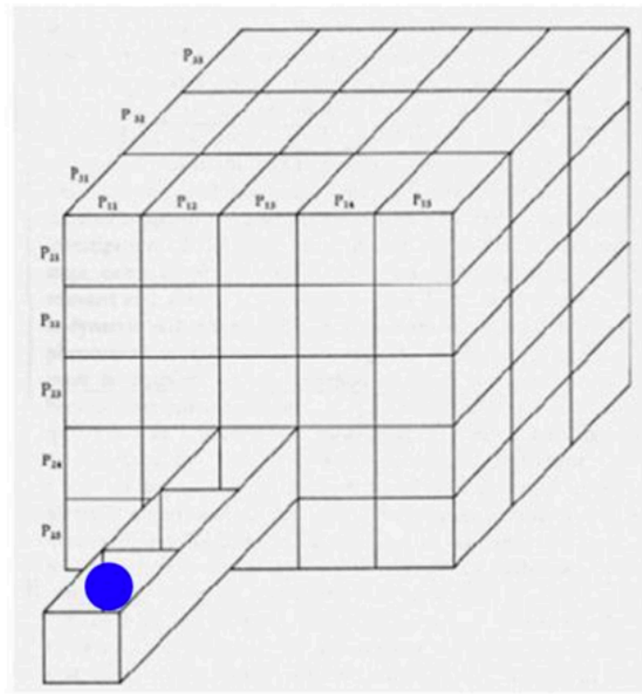


Fig. 11 Zwicky Box example (Zwicky, 1969) Image Credit: Fritz Zwicky

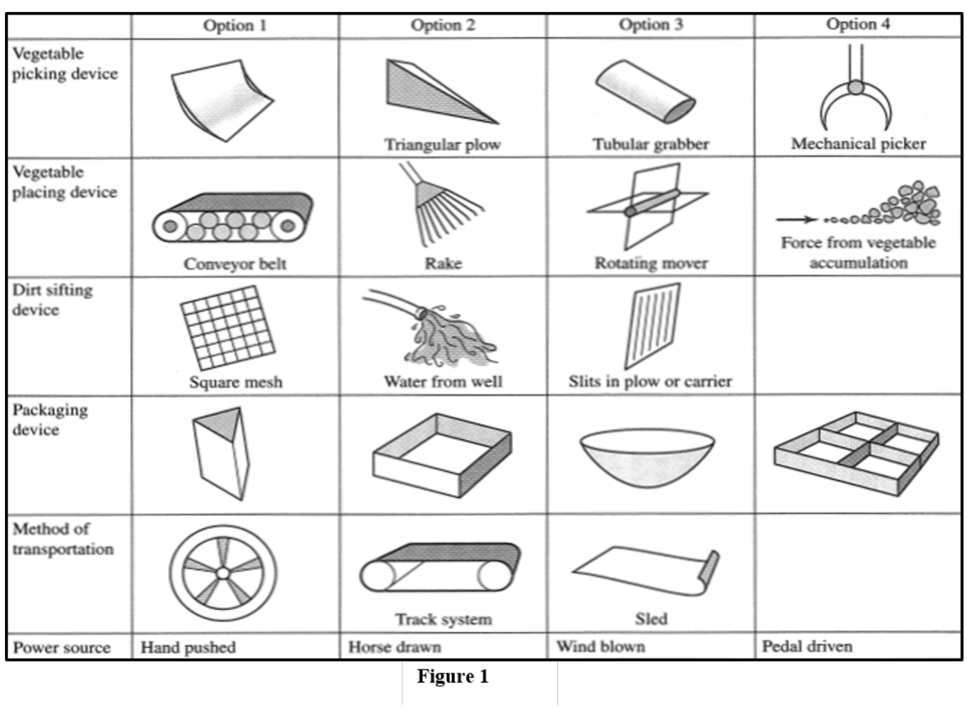


Fig.12 Example of a Zwicky Box in the form of a Morphological Chart

Credit: Coventry University, United Kingdom

Additionally, the Imagination card game titled “The Thing from the Future” asks players to collectively imagine objects from ranges of alternative futures through Sketching and Ideation. The objective of the game is to create entertaining but reflective descriptions of speculative Artifacts from “near-, medium-, and long-term futures.” Several prompts in the game describe the sort of future the Artifact comes from, emphasizing the “World Building” Method from Science Fiction Thinking. Players then sketch out or describe an object that comes from this universe. [162] For example, in an Apocalyptic universe focused on Health, we might see tattoos that track the health parameters of a person. The author has developed a functional “Spidey-Sense” device based on this Method. [101]

The Institute for the Future in California also supports the generation of “Artifacts from the Future.” In their words, “Artifacts from the Future provide a rich starting point for strategic discussions, whether for a new products team in a technical organization or a community group looking for ways to engage young people in building a stake in their own neighborhood. Creating Artifacts from the Future is also a great way to get people thinking about the future—their assumptions, their goals, and the path from here to there.” [163] Perhaps the parameters of this game can be altered specifically for Space Technology.

While these Methods may be supportive, interviews in this thesis show that Techniques: Sketching, Storyboarding, Prototyping are used more frequently than any specific Method in its entirety.

Chapter 7 | Synthesis

The Aerospace Industry, unlike the entertainment and Consumer Products industries, does not have a culture of recognizing the Design Discipline as a contribution to meeting core function goals and objectives. The argument of this thesis is that Design Methods and Techniques used by Designers have characteristics that can support space Mission Concept Development. Evidence shows that some teams within NASA and Aerospace companies are already utilizing the skills of Designers. There is an opportunity to increase the use of specific Design Methods and Techniques at certain phases of the flight mission lifecycle. Interviews in Chapter 5 and research into the history of the Design Discipline within NASA have revealed additional knowledge that goes beyond the narrowly defined research question. This Chapter shares the author's reflections on the overall learning from the study.

7.1 Answering the Research Question

This thesis has shown evidence of the use of Design Methods and Techniques in support of Aerospace and has presented Proposals for how these Design Methods and Techniques may be utilized further. Evidence from multiple interviews performed in this study implies that the activities of Aerospace teams can draw from several Design Disciplines, including Human Centered Design, Industrial Design, Entertainment Design and Graphic Design. Chapter 5 and 6 show evidence of answers to the author's research question: "What exploratory Design Methods and Techniques are currently utilized formally and informally within Aerospace and what barriers and opportunities exist to expanding these Methods and Techniques?" This research question is broken into two parts below.

Part 1

What Exploratory Design Methods and Techniques are currently utilized formally and informally within Aerospace?

Interviews show evidence that the following Design Methods and Techniques are currently utilized within Aerospace. Some Designers within Aerospace utilize elements of entire Methods informally. One example from interviews depicts a Designer selecting to utilize the Design Thinking Method's "Card Sorting" element, rather than the entire

Method. Aerospace Designers use Techniques more frequently than any specific Method as can be seen in Chapter 5 (Section 3). The Use Centered Design Method was shown to be used within NASA's Jet Propulsion Laboratory for the creation of a smartphone application. This instance is further described in Chapter 2 (Section 3).

Design Methods	Design Techniques
Design Thinking	Sketching
Human Centered Design	Prototyping
Imagineering Process	Storyboarding
Science Fiction Thinking	Collaging
User Centered Design	Photography
	Drawing

Part 2

What barriers and opportunities exist to expanding these Methods and Techniques?

Interviews and historical evidence show that a common barrier within Aerospace for Designers is cultural. Designers within Aerospace are seen to acknowledge that there is little knowledge within Aerospace of contributions offered by the Design Discipline, particularly within the Engineering Discipline. The development of a Design language and taxonomy for Aerospace may influence this barrier. The beginnings of a catalogue can be seen in chapter 4 (Section 3).

Opportunities exist within the space mission flight lifecycle to utilize Design Methods and Techniques. Evidence shows that Designers can support accomplishing goals and objectives within the different phases. These are further elaborated on in Chapter 6 sections 2,3 and 4.

Barriers	Opportunities
Lack of knowledge of the Design Discipline and its processes within Aerospace.	The flight mission lifecycle: Pre-Phase A, and Phases A, B, C, D, E, F.

7.1 Collected Stories

This section elaborates on personal stories that do not fall into the analysis of Methods and Techniques of this thesis. Information is collected from the author's work experience, coursework, personal stories and anecdotal evidence. Evidence has shown instances where unlikely collaborations when developing technology have resulted in intersections of Aerospace and Design, sometimes in serendipitous ways. This Chapter describes opportunities for the inclusion of non-Engineering Disciplines within Aerospace outside of the scope of the Methods and Techniques discussed in this thesis.

The National Academy of Sciences established a program in November, 2008 titled, "The Science and Entertainment Exchange." This program connects scientists and Engineers to film directors, script writers, actors and Concept Designers to promote accurate science in Storytelling in film and television. Normally, a scientist or Engineer might consult on a film or review a script for accuracy pro-bono. [164] It is theorized by the author that this relationship may also be of benefit the other way around. Concept Designers, film directors and writers may benefit the space mission development process through providing their expertise in Storytelling and Science Fiction Thinking.

In a NASA-JPL Center Innovation Fund workshop co-led by the author, this concept was tested when a Hollywood Concept Designer was invited to participate in the development of Astronaut devices and wearables for robotic interaction. Because the Design Thinking Method was the primary Method of data collection used for this workshop, imagery from Feature Film was used as reference. It is believed the inclusion of an experienced Concept Designer led to a variety of ideas inspired by science fiction, and provided the team of Engineers freedom to ideate within a realm they normally would not. The Concept Designer's background in working with materials for Feature Film additionally allowed for their input to spark interesting trains of thought. Additionally, this workshop resulted in a variety of concept sketches that served as markers for further technology development.

The author's work as a Designer in technology development includes Design and fabrication of robotics that use origami linkages for locomotion. [165] The Design Thinking Method, Sketching and Prototyping Techniques were used in the development of this work. In an example of coursework, The Science Fiction Thinking Methodology was used to develop an Artificial "Spidey-Sense" device, reflective of the comic book hero Spiderman's fictional power of enemy detection. [101] The author used an ultrasonic sensor connected to a vibration motor that was activated through proximity detection. [101] Research conducted by the author mentioned in Chapter 6 (Section 4) includes using Concept Design Techniques from Feature Film for space mission planning. [161] These examples support the Design Discipline's role in technology development and may be seen as opportunities for Design outside of the space mission life cycle.

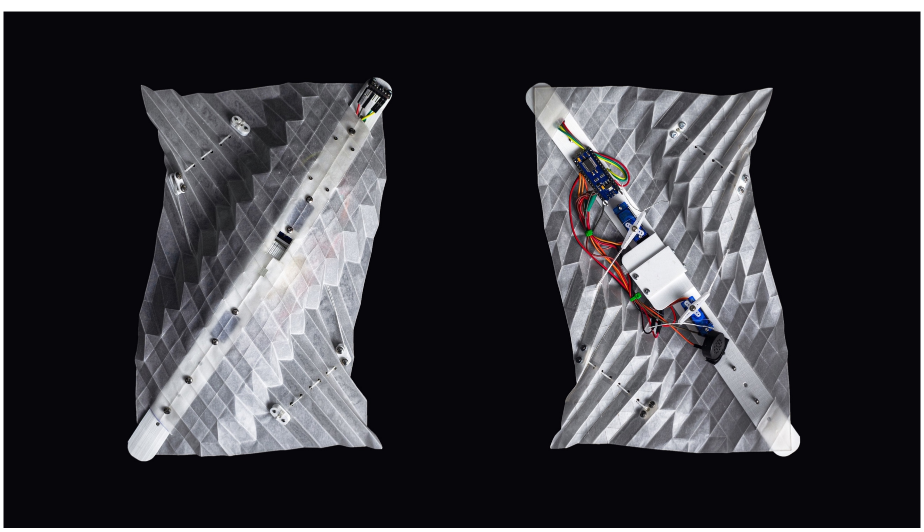


Fig.13 Origami Crawling Robot Designed from a flat sheet of vellum paper. The Design Thinking Method, Sketching and Prototyping Techniques were used for development of this robot. Image Credit: Jiani Zeng

Fig.14 The Science Fiction Thinking Method along with Sketching and Prototyping Technique were used for development of a "Spidey-Sense" device. Top: Illustrated Concept Design. Bottom from left to right: Motor driver, Ultrasonic sensor, Arduino Uno. Image Credit: Lizbeth B. De La Torre

In another example of a Concept Designer working in Aerospace, the career of Designer Ralph McQuarrie should be noted. An alumnus of the Bauhaus inspired institution, Art Center College of Design, Ralph began his career while working as a technical illustrator for a dentistry firm Designing equipment and teeth. In the 1960's he moved on to work at Boeing as a preliminary Designer for the Boeing company where he illustrated diagrams for the construction of the 747 Jumbo Jet. He later Designed Illustrations and posters for news coverage of the Apollo moon landing. [73] His work caught the attention of director George Lucas and he was recruited to imagine plans for his upcoming "space opera," Star Wars (1977). Ralphs Illustrations were instrumental in convincing executives at 20th Century Fox to fund the film and his Designs are still used by the Star Wars team today. [73]

Concerning the Art Discipline, the MIT Media Lab's "Space Exploration Initiative" are a team at the MIT Media Lab uniting Artists, scientists, Engineers and Designers to actively build the tools, technologies and human experiences of the world's sci-fi space future. They regularly deploy graduate projects that are often inspired by science fiction and Designate themselves as the first "Star Fleet academy," a reference to Star Trek's multidisciplinary teams. [166] Artist Nicole L'hulier and Designer Sands Fish fabricated and tested a cultural object for space in the form of a musical instrument for Zero Gravity. [167] This work showcases a technical capability of Artists and Designers to contribute to technology intended for space.

Fig. 16 Sands Fish and Nicole L'hulier showcasing their Telemetron in Zero Gravity Credit: MIT Media Lab

7.2 Contributions

This thesis fills a gap in literature by framing the current state of exploratory Design Methods and Techniques within space mission development and laying the groundwork to begin utilizing a wider variety of Design Methods and accompanying Techniques as seen in Chapter 7 (Section 1). The purpose of this thesis is to review the ways in which exploratory Design Methods and Techniques may be used in support of the space Mission Concept Development process. Design Methods and Techniques that may be beneficial to the process have not been documented previously in this manner.

This work creates a bridge between the Design and Engineering Disciplines within Aerospace by building a way in which the two fields can understand each other. This builds on previous research by MIT professor Maria Yang (2018, et al.). Professor Yang, in her paper "Design Principles: Literature Review, Analysis, and Future Directions," she proposes a formal approach to Articulating Design principles to "codify and formalize Design knowledge so that innovative, archival practices may be communicated and used to advance Design science and solve future Design problems." [168]

Additionally, this work may add to research by Dr. Tony Freeman and Dr. Tibor Balint, who, in their paper "Designing the Design at JPL's Innovation Foundry" have observed a need for Design and their processes within the early stages of space mission development at the Jet Propulsion Laboratory. [8]

7.3 Future Work

In order to test findings from this thesis concerning Design Methods and Techniques, the author would like to run a series of workshops that apply these Design Methods and Techniques described in Chapter 4 (Section 1) and 2 to the Space Mission Lifecycle. Participants would include subject matter experts, systems Engineers and Designers of the Human Centered Design, Industrial Design, Entertainment Design or Graphic Design Disciplines.

Additionally, more research is needed to document a history of the Design Discipline within NASA. The author hopes to mentor future Design researchers in this area at the masters or PhD level. Research in the history of the Design Discipline within NASA should include Artifacts such as NASA produced brochures, magazines, graphical assets and films from the 1940's through the 1990's. The presence of these artifacts imply the presence of a Designer within NASA and their specific disciplines at this time in NASA's history. These physical Artifacts from the 1940's through the 1990's are not easily found online.

Future work hopes to further explore the evidence in Chapter 7 of a possible reciprocal relationship between Feature Film Techniques and space technology development. Evidence shows a long history of collaboration between these two fields. Future data collection on this topic would include instances of collaboration similar to the work of Ralph McQuarrie in Chapter 7 (Section 1).

Conclusion

In conclusion, this thesis distinguishes between the Design and Art Disciplines while providing historical and recent examples of Design within Aerospace. Current, dedicated Design Teams within NASA centers are catalogued. Evidence from interviews suggests there are opportunities for the Design Discipline to be of support during Space Mission Concept Development. It was noted by Designers currently working in Aerospace that possible barriers for opportunities may be due to lack of knowledge of the Design Discipline.

Methods hypothesized as supportive within Aerospace include: Design Thinking, Human Centered Design, Science Fiction Thinking, and the Imagineering Process. Evidence from interviews shows elements of these Methods being utilized in various forms already within Aerospace, though rarely in their entire form. This thesis highlights that the Techniques discussed are beneficial to project outcome and used more often than the Methods within Aerospace. Initial evidence shows that an inclusion of Design Methods and Techniques may benefit the Space Mission Lifecycle, either in support of the systems Engineering Discipline, visual communication or reaching consensus during trade studies. In order for leaders of space missions to apply Design Methods and Techniques effectively, they will need to understand the purpose of each Technique and how to implement it in the context of their work. The results of this thesis provide a tool that project managers of space missions can use to select which Design Methods and Techniques may be utilized in each phase of their work on a space mission.

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