Tool, Object, Product (TOP) Function Analysis

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Introduction

Conventional Concept Development in Innovation

Reducing time to market has become imperative in competition, and the technology to generate breakthrough concepts and ideas has become the real key to success. Engineers recognize the difficulty of the task by failure to further improve a product significantly. Instead, any attempts to improve one parameter of the product leads to deterioration of another parameter. Having limited time, no guide to solve problems in innovation, and, as a result, failing to develop breakthrough solutions, they select trade-off solutions, fearing that a competitor could have a better result. In addition, project teams are not sure that all problems that are worth solving are revealed and considered.

Today to be successful in product development, there is a need to develop an exhaustive set of concepts comprising all possible developments of the product. This need requires the formulation of all product-related problems worth solving and the successful solving of those problems.

The Theory of Inventive Problem Solving

All problems in innovation are unique, so it is not obvious that a step-by-step guide could be used to solve all of them. Common thinking accepts recommendations such as “be creative,” “generate as many ideas as possible,” “think about your problem all the time,” “hire ‘out-of-the-box’ thinkers,” etc.

Recognizing generic types of problems in innovation was the key to developing the ***Theory of Inventive Problem Solving*.** TRIZ (the Russian acronym for the theory) is the knowledge-based, systematic approach to innovation. Developed in the former Soviet Union by Genrich S. Altshuller (1926-1998) and his school, TRIZ methods are drawn from analysis of the most innovative inventions in different industries, technologies, and fields of engineering.

The power of TRIZ is based on utilizing trends in the evolution of successful products, ways to overcome psychological barriers, and generalization of the ways used to solve problems in the most innovative inventions.
TRIZ involves a systematic analysis of the system to be improved and the application of a series of guidelines for problem definition. TRIZ classifies innovative problems and offers corresponding problem-solving methods for each class of problem.

TRIZ analysis of the system to be improved includes an integrated system approach, function analysis, and function modeling. In problem formulation and problem solving, TRIZ aims to maximize utilization of the resources of the product or process, its supersystem, and its environment.

Since Altshuller stopped development of TRIZ, his followers have continued its development. Extensive practice had dictated the need for improving the effectiveness of revealing problems to solve, integration of TRIZ methods, and their further development.

Function Analysis

Altshuller understood the importance of a function approach in problem solving since the earliest days of TRIZ. For example, his concept of the Ideal System says that the Ideal System performs its function but does not exist, which means that the Ideal System performs its function for free and with no harm. However, the need for integration of Function Analysis into TRIZ was recognized after developing methods to solve generic problems in innovation.

Function analysis plays the key role in problem formulation. This paper describes an advanced development called TOP Function Analysis and its advantages.

Substance-Field Analysis

Altshuller developed a method and a set of symbols for describing generic types of problems and their solutions. The method was called Substance-Field Analysis (SFA).

Altshuller’s model of the simplest useful system is composed of three elements — the two substances and the field.

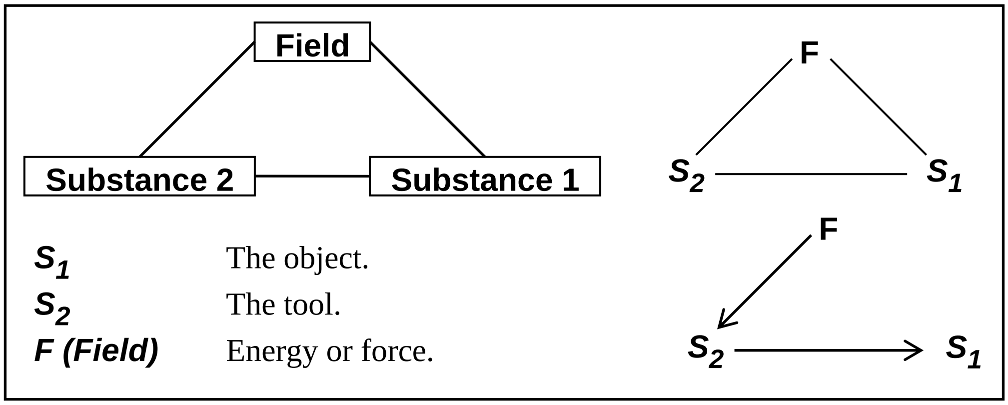


Figure 1. Models of the simplest useful system

Figure 2. Models of an incomplete useful system

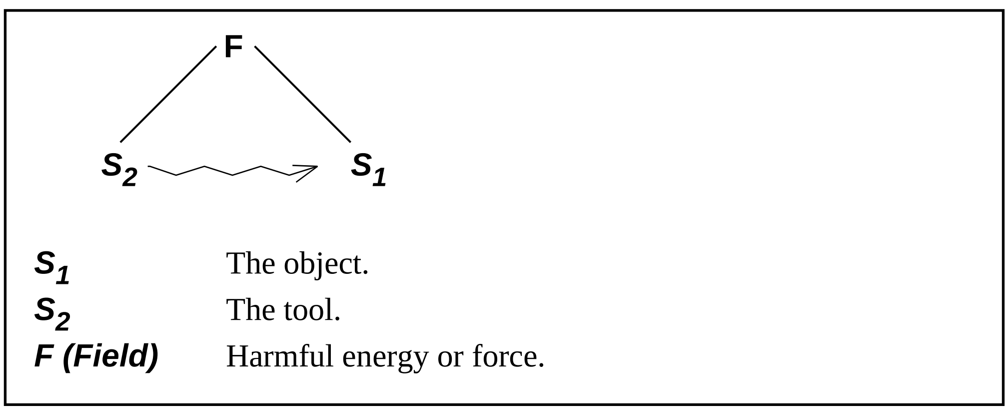


Figure 3. Model of the simplest system having a harmful action

Althsuller's Substance-Field Analysis enables you to describe models of systems to be improved and models of improved systems. A set of 76 most effective generic transitions of models toward models of improved systems he called Standard Solutions to Inventive Problems.

Substance-Field Models describe models of the systems rather than functions. However, in order to support Function Analysis, you need to describe models of the functions.

Tool-Object-Product (TOP) Function Analysis

Tool-Object-Product (TOP) Analysis, the next generation of Substance-Field Analysis, was developed by Zinovy Royzen in 1989. The simplest useful function has four components. It has the tool of the function (or the function provider), the object of the function (or recipient of the action of the tool), the action of the tool at the object, and one more component — the product of the function. The useful function of the tool is to obtain the product of the function from the object. The action is described by one arrow, which simplifies the model.

$$T \xrightarrow{F} O \Rightarrow U.P.$$

O	The object of the useful action
T	The tool of the useful action
F (Field)	Energy or force, or description of the useful action
U.P.	A useful product.

Figure 4. Model of a useful function

$$T \overset{F}{\rightsquigarrow} O \Rightarrow H.P.$$

O	The object the harmful action
T	The tool of the harmful action
F (Field)	Energy or force, or description of the harmful action
H.P.	A harmful (unwanted) product or products

Figure 5. Model of a harmful function

Very often a useful action also causes an unwanted effect, or an attempt to improve a function leads to deterioration in another function of the system. Conflicts are the most difficult type of problem in innovation. TRIZ offers models to describe any type of conflict.

$$T \begin{array}{c} \xrightarrow{F_u} \\ \underset{F_h}{\rightsquigarrow} \end{array} O \begin{array}{l} \Rightarrow U.P. \\ \Rightarrow H.P. \end{array}$$

O_1	The object of the useful and the harmful function
T	The tool of the useful function
F_u	Energy or force, or description of the useful function
F_h	Energy or force, or description of the harmful function
U.P.	A useful product.
H.P.	A harmful (unwanted) product or products

Figure 6. Model of a conflict

Modeling a function by describing all four components — the tool, the object, the action, and the product — improves understanding of both the function and the best ways for its improvement.

The following subsections describe some of the advantages of TOP Function Modeling:

Generic Model of a Function

Neither the tool of the function nor the object of the function has to be a substance. TOP Function Modeling allows you to model any function in any system. It is a more generic way to model a function than Substance-Field Modeling.

Precise Description of a Function

Desired and unwanted products of the functions of a modeled system improve understanding of the system and simplify analysis of the system resources.

Link Between Functions

Introducing the product of a function into its model provides a very convenient and understandable link between functions. For example, a product of the first function can be a tool or an object of a subsequent function.

The link between functions is important in understanding not only a desired performance of a product, but also the chain of unwanted functions. Links between functions simplify cause-effect analysis and improve the process of revealing the cause of a current or potential failure of a product.

Increasing Effectiveness of Function Analysis

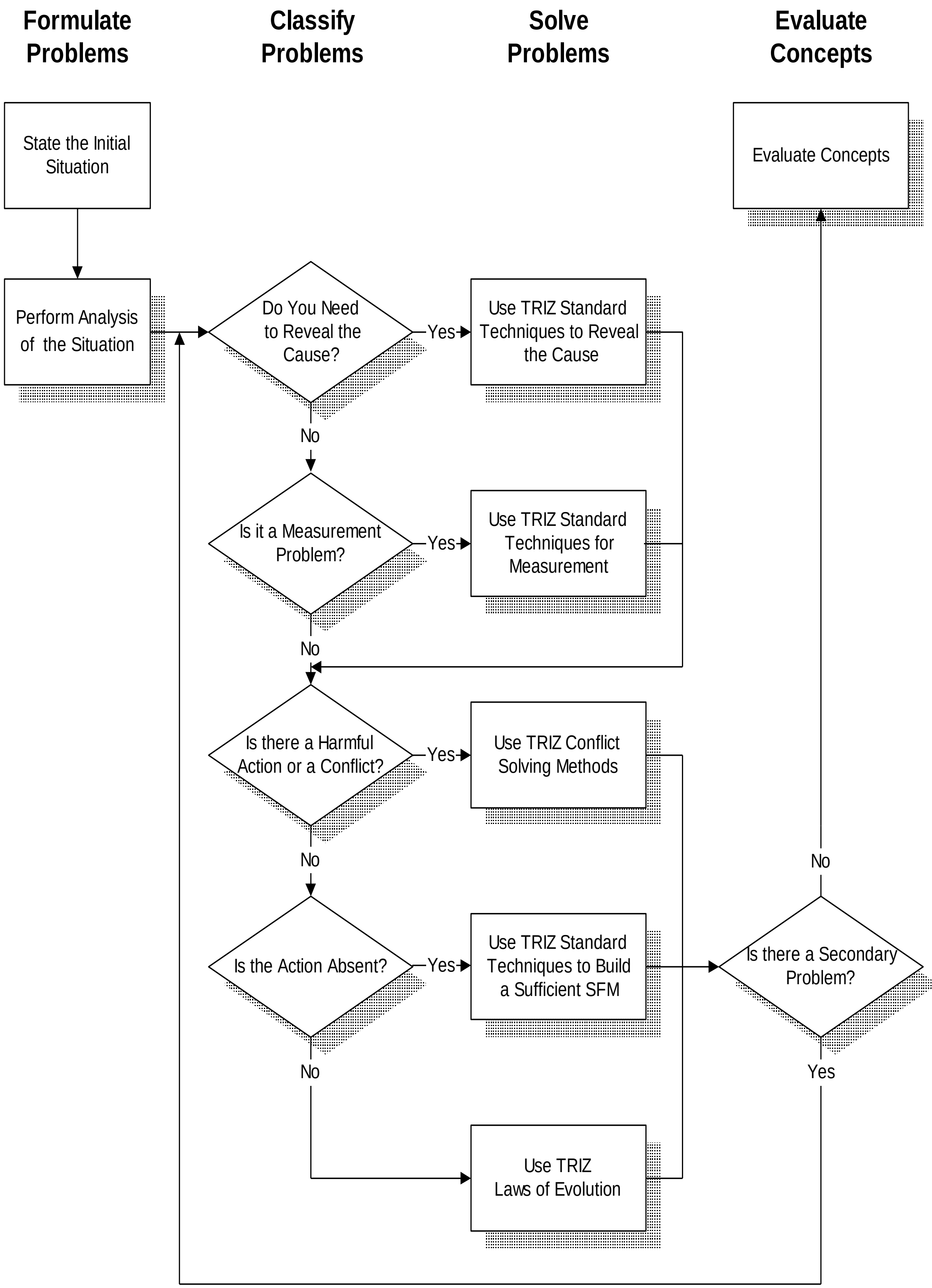
Function analysis guides you in decomposing the performance of your product into single functions — both useful and unwanted. The system approach guides you in describing the function of the supersystem of your product and interactions between the product and its supersystem. It also guides you in analyzing and describing interactions between the product and its surroundings that are not part of the supersystem. Then a single function can be considered separately if it needs improvement.

TRIZ offers five basic function models:

1. Adequate useful function (may require technological forecast)
2. Insufficient useful function (requires improvement)
3. Absent useful function (requires introduction)
4. Harmful or undesired function (requires elimination)
5. Unknown undesired function (requires revealing the cause)

Function modeling helps you to understand the system's performance, state the set of problems to consider, rank priority of the stated problems, classify the problems, and determine the TRIZ Methods to be applied according to the following TRIZ Flow Chart.

TRIZ Flow Chart



A Key to Advanced Development of Problem Solving Methods
TOP Function Modeling has allowed further development of problem solving methods and their integration:

Ideal Ways is an analytical method made up of the ideal directions for improving a function. Ideal Way 1, for example, guides you in stating problems related to the possibility of elimination of the function and its tool. The TOP model of the analyzed useful function provides the possible ways — eliminating the need for the product of the function or eliminating the object of the function.

TRIZ Conflict Solving Methods include TRIZ Standard Techniques, ARIZ, and Inventive Principles.

TRIZ Standard Techniques is a further improvement of Standard Solutions, developed by Zinovy Royzen. Standard Techniques are step-by-step guides for applying generic solutions to your problem and developing specific solutions by utilizing the resources of the system, its supersystem, and its environment.

TRIZ Standard Techniques include:

- Six techniques for direct elimination of a harmful or unwanted function (Direct Ways)
- Seven techniques for indirect elimination of a harmful or unwanted function
- Three techniques for elimination of the consequences of a harmful function
- Three techniques for converting a harmful action into a useful function

(Direct Ways provides a set of generic techniques for preventing an unwanted function from producing its unwanted product. Indirect Ways is a set of generic techniques for eliminating harm form an unwanted product.)

These techniques guide you to consider a complete set of the best approaches to dealing with a situation where an unwanted function is involved. This set of best generic approaches leads to an exhaustive set of concepts. The ideality of solutions depends on the availability of resources and the current constrains, which change over time.

Further development of ARIZ and its integration into the process of concept development.
Integration of ARIZ and initial function analysis of a system has improved conflict definition and eliminated repetition. TOP modeling improves understanding of the conflict, its opposite versions, the function of X-resource and its product. One of the most difficult steps in ARIZ – formulation of the physical contradiction — is simplified significantly. Integration of TRIZ Methods allowed reducing the number of steps in ARIZ and improving its effectiveness.

A Hard Drive Problem

A hard drive has an actuator arm, which can move relative to a magnetic disk that is rotated by an electric motor. At the end of the arm is a read/write head, which can magnetize or sense the magnetic field of the disk. The head is separated from the surface of the disk by airflow generated by the rotating disk. The gap between the head and the disk is very small. Any contact between the head and the magnetic disk may cause loss of data.

The disk has a landing zone, where the head is positioned when the disk is not spinning. The landing zone is an area of the disk where no data is stored. When the computer is switched on, the disk starts spinning, creating an airflow, which lifts the arm, and creating the required gap. Then the arm is moved away from the landing zone to read and write data. When the computer is turned off, the arm is returned to the landing zone. Slowing of the spinning disk decreases the airflow supporting the arm. As a result, the arm rests on the landing zone.

Applying an external force to the drive (such as moving or knocking the computer), can move the head away from the landing zone and destroy data on the disk. A latching mechanism is used to prevent the arm from moving when the computer is not in use. A permanent magnet holds the arm when the head is in the landing zone. When the computer is turned on, the arm has to overcome the latch magnet in order to move.

Figure 7. A hard drive

Problem

The drive needs to be protected against stronger external force. This could be achieved by replacing the current latch magnet with a stronger one. But the arm would not be able to overcome the force of any magnet stronger than the current one. Thus an attempt to improve the reliability of the hard drive causes deterioration of its performance.

A breakthrough solution is needed to improve the reliability of the drive without any deterioration of its performance, while minimizing any increase in production costs.

Summary of Functional Analysis

The latching mechanism includes the latch magnet, a plastic holder for the latching magnet, and a screw. The function of the latch magnet is to hold the arm.

$$\textit{Magnet} \xrightarrow{\textit{Magnetic Field}} \textit{Arm} \Rightarrow \textit{Arm}_{\textit{held}} \quad \textit{(Useful function.)}$$

The performance of the latch magnet is insufficient according to the requirements for a new design.

$$\textit{Magnet} \overset{\textit{Magnetic Field}}{\dashrightarrow} \textit{Arm} \Rightarrow \textit{Arm}_{\textit{held}} \quad \textit{(Useful insufficient function.)}$$

A stronger latch magnet will hold the arm adequately, but the arm will not be released.

$$\textit{Stronger Magnet} \xrightarrow{\textit{Magnetic Field}} \textit{Arm} \Rightarrow \textit{Arm}_{\textit{held}} \quad \textit{(Useful function.)}$$

$$\textit{Stronger Magnet} \underset{\textit{Magnetic Field}}{\rightsquigarrow} \textit{Arm} \Rightarrow \textit{Arm}_{\textit{not released}} \quad \textit{(Unwanted function.)}$$

Figure 8. Model of the conflict

Application of Ideal Ways

Ideal Way 1. Eliminate the need for the function of the magnet.

$$\textit{Magnet} \xrightarrow{\textit{Magnetic Field}} \textit{Arm} \Rightarrow \textit{Arm}_{\textit{held}} \quad \textit{(Useful function.)}$$

The arm has to be held in order to prevent it from moving while the computer is not in use. We need to correct the model of the function.

$$\textit{Magnet} \xrightarrow{\textit{Magnetic Field}} \textit{Arm}_{\textit{moving}} \Rightarrow \textit{Arm}_{\textit{held}} \quad \textit{(Useful function.)}$$

Problem 1: If the moving arm cannot damage the disk, there is no need for holding the arm.

Problem 2: If the arm cannot be moved by the external force, there is no need for holding the arm. This statement requires analysis of the chain of unwanted actions that causes the unwanted motion of the arm.
Unwanted action: The arm is moved by its pin.

$$\textit{Pin}_{\textit{moving}} \overset{\textit{Mech. Field}}{\rightsquigarrow} \textit{Arm} \Rightarrow \textit{Arm}_{\textit{moving}}$$

Problem 3: The motion of the pin caused by an external force has to be eliminated.

Unwanted action: The pin is moved by the drive case.

$$\textit{Drive Case}_{\textit{moving}} \overset{\textit{Mech. Field}}{\rightsquigarrow} \textit{Pin} \Rightarrow \textit{Pin}_{\textit{moving}}$$

Problem 4: The motion of the case caused by an external force has to be eliminated. Unwanted action: The drive case is moved by the computer chassis.

Chassis *moving* ~~~***Mech. Field***~~~> ***Drive Case*** ⇒ ***Drive Case***$_{moving}$

Problem 5: The motion of the chassis caused by an external force has to be eliminated.

Ideal Way 2. Replace the latch magnet.

X
~~Magnet~~ ————> ***Arm*** ⇒***Arm***$_{held}$ ***(Useful function.)***

A. X=a resource
B. X=an alternative way to hold

The list of resources includes the resources of the latching mechanism, the drive, and the surroundings. Analysis of the resources revealed the possibility of replacing the latch magnet. All resources have to be tried as X.

One possibility: The arm carries a voice coil. Interaction between the magnetic field created by an electric current through the voice coil and the magnetic field of the voice coil magnets swings the arm around the pin. The latch magnet could be replaced by a much stronger voice coil magnet. In this case, there would be no need for the latch magnet, its plastic holder, and the screw. In mass production of the hard drives, the solution could save a lot of money for the manufacturer.

Another possibility: The external force itself could be used to hold the arm instead of the latch magnet. The solution looks like a "safety belt" for the arm.

The requirement to consider alternative ways to hold the arm lead to analysis of a variety of locking mechanisms used in different industries.

Ideal Way 3. The arm held by a stronger magnet has to be released when necessary.
Problem 6: It is necessary to eliminate the unwanted holding force of a strong magnet when necessary. There is a conflict:

Stronger Magnet —***Magnetic Field***—> ***Arm*** ⇒***Arm***$_{held}$ ***(Useful function.)***
Stronger Magnet ~~~***Magnetic Field***~~~> ***Arm*** ⇒***Arm***$_{not\ released}$ ***(Unwanted function.)***

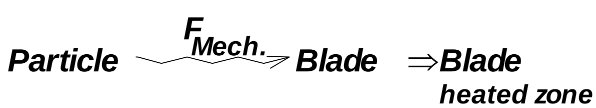
An Oxidizer Turbopump Problem

An oxidizer turbopump is one of the most complex and expensive components of a Space Shuttle Class Main Engine (SSCME). It feeds the main combustion chamber with oxygen. The turbine of the oxidizer turbopump is rotated by a high velocity flow of very high temperature oxygen, called GOX (gas oxygen). The turbopump is made of material that resists working temperature oxygen.

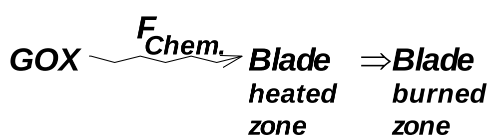
Failure of the oxidizer turbopump can be caused by a dust particle or other wearing particle in the GOX. Colliding with the hardware, a particle, having a very high velocity because of the flow of GOX, would increase the temperature of the hardware in the proximity of the collision to a level beyond which its material could not resist the oxygen. Ignition of the hardware generates more heat and could result in complete failure of the oxidizer turbopump and, as a result, the complete failure of the whole engine.

Summary of Analysis of the Failure

Problem 1. A particle collides with hardware (for example, with the turbine blade).



Problem 2. The heated material of the blade does not resist the oxygen.



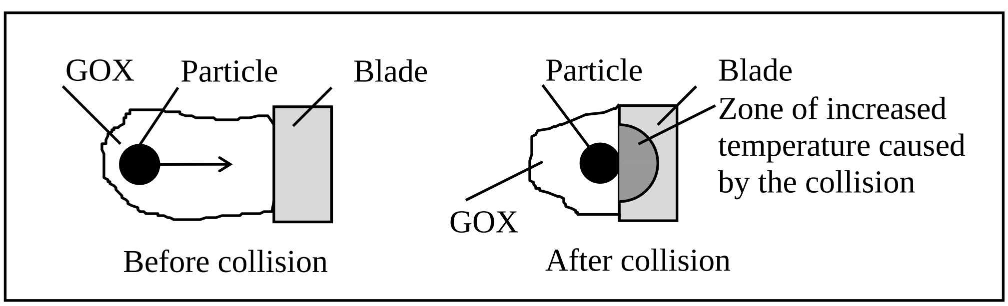


Figure 10. Analysis of the zone of the harmful action

Analysis of the SSCME

The engine includes a tank with liquid hydrogen, a tank with liquid oxygen (LOX), the main combustion chamber, and the nozzle.

The fuel (liquid hydrogen) passes through a high-pressure fuel turbopump before cooling the main combustion chamber and nozzle. The fuel is vaporized during the cooling process. After cooling, the fuel is split between two preburners.

The preburner of the fuel turbopump is fed by a fuel-rich mixture. The preburner produces a high velocity flow of high temperature hydrogen that rotates the turbine of the fuel turbopump.

The preburner of the oxygen turbopump is fed by an oxygen-rich mixture, composed approximately 98-99% of oxygen. The oxygen turbopump preburner produces a high velocity flow of high temperature oxygen that rotates the turbine of the oxidizer turbopump.

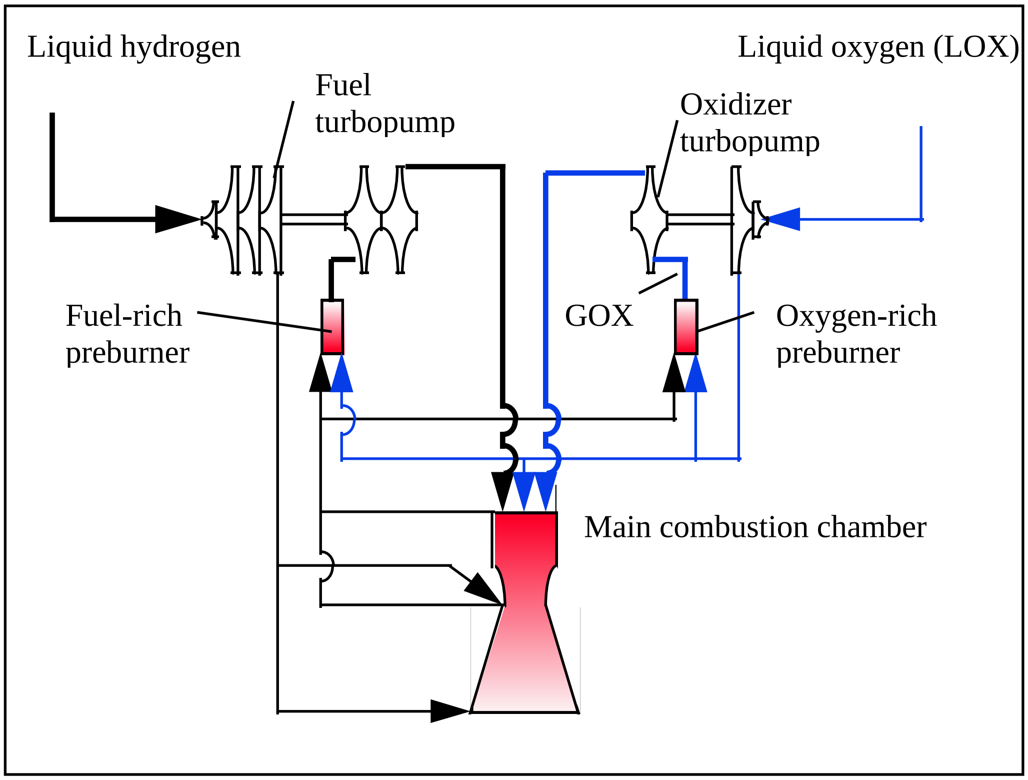


Figure 10. Simple schematic of SSCME

Summary of Application of Direct Ways

Problem 1
Application of Direct Ways to Problem 1 led to formulation of the following approaches to solving the problem.

1. Try to insulate the blade from the particle.

2. Try to introduce a field that will prevent the collision (for example, by repelling the particle).
3. Try to protect the blade by capturing the particle before it reaches the blade.

4. Try to modify the particle to make it harmless in the case of collision (for example, melt or evaporate the particle).

5. Try to modify the blade to be nonsensitive to the collision (in other words, so the collision would not increase the temperature of the blade). This approach leads to formulation of the following physical contradiction: the temperature of the blade has to be increased by colliding particles, but the temperature of the blade must not be increased to the point of resisting GOX.

Problem 2

Application of Direct Ways to Problem 2 led to formulation of the following approaches to solving the problem.

1. Try to insulate the heated blade from the GOX. A technology to plate the hardware of the oxidizer turbopump with ceramic is known. This technology was developed in Russia. It is a very expensive technology. In addition, the ceramic plating would increase the weight of the engine. Furthermore, if the ceramic is not strong enough, it could cause engine failure.

2. Try to modify the GOX. If GOX is replaced by hydrogen, for example, the possibility of burning the hardware will be eliminated completely. This technology is known as a Fuel-Rich Staged Combustion Cycle Engine System. It has another potential for failure if high-temperature hydrogen mixes with the pumped oxygen in the oxidizer turbopump.

3. Try to reduce the temperature of GOX. The technology reducing the temperature of GOX without any reduction of the power of the oxidizer turbopump is known as a Full-Flow Staged Combustion Cycle Engine System. The power of the turbopump depends on the velocity and mass of the driving flow. In the known technology, all oxygen that is not directed to the fuel turbopump preburner passes through the oxidizer turbopump. Increase of the mass of the driving flow reduces the required velocity, resulting in reduction in the temperature of GOX.

4. Try to modify the heated blade. Try to increase the resistance of the blade material to oxygen. This is a materials problem. Materials having high resistance to oxygen do not necessarily have strong mechanical strength. Increasing the resistance of the material to oxygen very often causes increase of the weight of the turbopump.

5. Try to cool the blade to the working temperature, at which it resists oxygen. This raises subsequent problems: how to cool the heated blade and how to keep the temperature of the cooled zone of the blade from falling below the working temperature (otherwise, the performance of the pump would be deteriorated). An obvious resource for cooling the blade is LOX. But using it as a coolant presents some constraints: it is difficult to maintain working temperature by cooling using LOX, and it is difficult to have LOX in the time and place of an accidental collision.

TRIZ requires consideration of all resources, including GOX and the blade itself. From analysis of the simplified schematic of the engine, it is known that GOX is not pure oxygen. GOX includes 1-2% of water vapor as a result of burning hydrogen. Water vapor is an excellent coolant. It is already at the working temperature and ready to cool the blade down to the working temperature. It was necessary to make calculations to determine how much water vapor is required, but the concept does not require any changes in the hardware of the engine.

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