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A TRIZ View on Air Navigation Evolution

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Abstract – The article illustrates some concepts related to the patterns of evolution of technical systems as seen in TRIZ and their identification at the level of air navigation systems. **Keywords: TRIZ, Multi-Screen, System Operator, Ideality**

I. INTRODUCTION

Any technical system is part of a Super-system and is made of different Sub-systems. When solving a non-typical engineering problem it is very important, during the process of building the solution, to keep in mind a picture not only of the specific technical system we have to modify or improve but of the super-system to which it belongs, of the sub-systems which it involves, and all of these have to be visualized in the past, present and future, and sometimes even as Anti-systems. This is not an easy task to accomplish but we already know [4] that TRIZ offers a specific tool for doing it: the Multi-Screen Approach also called the System Operator [4]. One question arises when using this tool: are the transformations suffered by the chosen system the ones that are necessary for the system to evolve towards its Ideality [5]? One cannot answer this question unless referring to the patterns of evolution of technical systems [3]. In this article I will detail some "general tendencies of technical system evolution" [1] and try to identify them in the evolution of air navigation systems.

II. STAGES

The following criteria were used by Altshuller [1], the father of TRIZ, to evaluate the evolution of a technical system: structure of the system; (P) - different kind of problems which appeared on the evolution path; (M) - mistakes made by the people trying to develop the system and (D) - basic directions of evolution.

I will use the criteria as stated by Altshuller and try to identify a correspondence between the levels they define and the important stages in the history of air navigation since the moment of its appearance and up to the present:

- Pre-System Level: Independent Objects:

A|B|C...

- P: some objects reach the plateau of their development and utilization.
- M: the desire to continue improving these objects
- D: consolidation of independent objects into a system.

Once the first machines allowing man to fly appeared and before these came to be part of an air transportation system, under the constraint of the *necessity* to "ensure the navigation of the aircraft in conditions of safety" [6], different technical objects were used to achieve this. I selected two events in the history of navigation that would illustrate this level of evolution. The first refers to Bleriot's flight from Dover to Calais in July 1909 without instruments of navigation, the identification of the landing place being achieved by waving a French banner [6]; the second is G.Chavez's flight over the Alps in September 1910 carried out with the help of a map (object A) and a barometer (object B).

- Transition level: Primary unstable system:

A+B+...

- P: absence of necessary system parts; wrong parts being incorporated; parts interacting poorly.
- M: introduction of the most highly developed object from the series A1, A2, A3...
- D: search for a "Cinderella" object; replacing the missing object with a person (H).

An example to illustrate this level is the flight of three Curtiss aircrafts over the Atlantic in May 1919 during which twenty-one destroyers, which served as visual and radio navigation aids, and communication links [A+B+...], as well as providers of weather and rescue services, were on station at intervals of 50 miles between Cape Race, Newfoundland, and Corvo, the farthest island West of the Azores. In spite of the adopted security measures, only one of the three crafts reached its destination overcoming many difficulties. In 1919 the radios used were primitive and unreliable and there was a lack of instruments that would have allowed for navigation across large areas of sea covered surfaces. Therefore, finding the "zero point" for landing on a tiny island amid hundreds of square miles of ocean was not an easy endeavor.

- Stable system: objects become part of the system, with each part working independently:

A+H+B+H+C+H...

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- P: resources of system development limited only by the capacity of the human portion of the system
- M: desire to improve only parts A and B ... while preserving parts H.
- D: replacement of human (H) parts with device (D).

The newly created system, although not entirely perfected, already receives new utilizations for example mail delivery. To facilitate navigation a huge network of light beacons was deployed in the USA. A beacon consisted of a parabolic mirror and a rotating lamp flashing every 10 seconds. This allowed night flights to be performed. At the same time "dead reckoning" [7] (estimating one's current position on the basis of a previously determined position, or fixing, and advancing that position on the basis of known speed, elapsed time, and course) was the primary navigation method used. It is the method on which Lindberg relied on his first trans-Atlantic flight. A pilot used this method when flying over large bodies of water, forest, deserts. It demanded more *skill and experience* than piloting did. It was based only on time, distance, and direction. The pilot had to know the distance from one point to the next and the magnetic heading to be maintain. The pilot *worked* on the pre-flight plan chart, he planned a route in advance. The pilot *calculated* [A+H...] the exact time when he would reach his destination while flying at constant speed. In the air, the *pilot used the compass* [B+H...] to keep the plane heading in the right direction. The first LF navigation systems transmitted two Morse-codes, letter A, point, line, and letter N, line, point, using a bandwidth between 190 to 535 kHz. They transmitted a powerful beacon (1500 watt), spaced at a distance of 200 miles. The pilot was guided by the beacon behind him for 100 miles and then by the beacon ahead of him for the next 100 miles. The beam width being only about 3°, it was important for the pilot to rapidly tune in to the station ahead of him. The sub-systems were not yet specialized: when radio stations were located near the airport, one of the beams which was lined up with the runaway was used for landing under low-visibility conditions. Although radio beacons represented a milestone in instrumental flight, there were quite a few limitations proved by the following assertion: "When flying through mountain passes in IFR (Instrumental Flight Rules A/N) weather or on a dark night, the pilots paid close attention to the tones in their headphones. Palms became moist in the cockpit when static from electrical storms interfered with the reception of those crucial signals - or when beacon signals bounced off the canyon walls and gave false information"[8].

- Transition level: Unstable system; device Dh copies human actions: A+Dh+B+Dh+ ...

- P: Devices Dh limit the ability of the entire system
- M: improvements of each separate element without considering that they compose now a complete system
- D: transition from mechanical set of parts to organically interwoven synthetic system of elements.

Air navigation is no longer limited by man's orientation abilities and his speed of reaction; the equipment on board the plane allows for navigation under the most different circumstances: nighttime, fog, or storms. Much of the equipment still imitates the old pattern of orientation, for example the ground light beacons are replaced with different types of radio signals which the members of the crew have to identify and manually measure; the crew is made up of operators specialized in navigation; board instruments, grouped by their function, are clearly separated depending on their users: the pilot, the mechanic, the navigator. Old principles are taken over in order to build instruments meant to measure elements that could be used in establishing the trajectory of the aircraft. The altimeter (a kind of barometer) appears around 1913-14. It is perfected in 1929 when its precision is increased (as a sub-system of the navigation systems, it independently follows a similar evolutionary curve reaching the apogee of its evolution by the use of its initial fundamental principle, that of the aneroid barometer). Further improvements at the level of the altimeter as an independent navigation instrument are connected with the appearance of the servo-altimeter, to which the mechanical part is reduced by an inductive method. Later on the radio-altimeter is devised using a different physical principle, respectively the properties of the radio waves. In the 1930s and 40s within the generalization of the procedure involving radio connection with the ground, the communication of the data on atmospheric pressure at the destination airport prefigures the future integration of this information in a super-system (Aeronautical Fixed Telecommunication Network). Other instruments were developed: the speedometer (for horizontal speed), the variometer (for vertical speed). The steps in the evolution of these instruments were similar, starting with the use of the principle for pressure measurement and continuing with the use of an electrical transducer. We can also mention the magnetic and gyroscopic compass and, in conformity with natural evolution, the gyromagnetic and gyroinductive ones. All these independent navigation instruments, although they represented a step forward, could not by themselves ensure sufficient accuracy in maintaining the direction of the flight.

- Stable system; some of its parts become element E of the system, and as a rule, they can work only together: E1+E2+E3+ ...

- P: when one improves an element while significantly worsening other elements (or the entire system), the technical contradiction appears.
- M: desire to gain in one area without consideration of the losses in another.
- D: development of specialized systems.

The information coming from the diversity of instruments on board the aircraft start being used in a more sophisticated way, by the correlation of different information and their use at he level of complex systems of navigation (Sperry C-9, Collins FD-108, etc.). We can include here the VHF Omnidirectional Range navigation system (VOR) whose introduction began in the early 1950s and which is by far one of the most important inventions in air navigation. The VOR facility transmits two signals at the same time: one signal is constant in all directions, while the other is rotated about the station. The aircraft equipment receives both signals, compares electronically the difference between the two signals, and interprets the result as a *radial* from the station. The Instrument Landing System (ILS), the first of which was installed for testing at the Indianapolis airport in 1940, must also be mentioned.

- Specialized, stable system: E1'+E2'+E3'+ ...

- P: as the system specializes further, its area of utilization shrinks, down time increases and efficiency declines.
- M: desire to continue specialization.
- D: reconstruction of complete system transition to other physical or chemical principles of action.

The development of the same navigational systems, VOR/DME and NDB, continues; no new navigation principle appears, except some new concepts such as "free flight".

- Transition level: the E1'E1"+E2'E2"+... combination becomes an unstable system.

- P: significant increase in system complexity; reduction of ability for development.
- M: continuous search for different combinations of elements (subsystems).
- D: transition to other physical or chemical principles of action.

VOR/DME were still at the basis of controlling for the majority of flights; LORAN-C remains the newest navigational system in general use; OMEGA the most commonly used as a stand-alone, long-range navigational system. Instead of Instrument Landing System, the MLS (the microwave landing system) is outlined based on a new principle.

- Stable system: SuS1+SuS2+SuS3+ ... elements of the system rapidly develop into subsystems (SuS)

- P: the system development at some point gets into conflict with outside environment by creating unacceptable changes in it.
- M: desire to smooth out conflict by adding intermediate sub-systems.
- D: transition from an open system to a closed one, which is independent from outside environment.

Air navigation becomes an activity with global implications but there are great differences between the levels reached by the composing parts. EFIS (the electronic flight information system displays) becomes imperative even if limited to the latest model airplanes. The most important negative impact on the medium is at the level of the super-system - the pollution of the atmosphere by the ever increasing number of crafts.

- Transition level: unstable system; during the working cycle an enclosed system is activated.

- P: complication of design; limited time of action.
- M: continuous development of different sub-systems.
- D: reconstruction of complete system: transition to new principles of action.

The present navigation systems haven't all reached this level, but EFIS, INS (inertial navigation system) and GPS (global positioning system) assert themselves rapidly. It is interesting to notice that INS appeared in Germany around 1910 without having a practical usefulness, which can be explained by the fact that the other elements of air navigation were far from this level of evolution and therefore impossible to integrate in this context. INS was an autonomous system, with no ground correspondent and which, starting with 1932, due to military reasons, was developed for ballistic applications. It was only in 1950 that civil applications were transferred to it.

- Stable closed system

- P: the number of sub-systems rapidly grows.
- M: continuous development of a system and its sub-systems.
- D: transition to super-system; the given system becomes an element of another system at a much higher level.

- The self developing system.

The last two levels correspond to systems with a high degree of ideality. At the present stage of development aircraft fly respecting the same physical laws as before and no fundamentally new principles appeared in navigation. However, not even the most optimistic people could imagine that the life of a whole range of promising navigation systems, such as the MLS replacing the ILS, would be rapidly shortened by the GPS system; that EFIS would become standard:; while at the level of the instrument panel, the Synthetic Vision System would be devised, which integrated information from multiple sensors including infrared video cameras and laser radars that provided real-time, panoramic viewing for pilots and crew via sensor and synthetic data fusion.

It is difficult to predict the evolutionary tendencies of air navigation both at the level of the super-system and the level of the sub-systems but, most certainly, the above tendencies will be confirmed and the present challenges connected with the use of polluting fossil fuels and the tremendous growth of air traffic will trigger the use of fundamentally new principles which will lie at the basis of future transportation systems and air navigation.

Technical systems, and not only, follow a life which can be represented by a curve, the so called S-curve, showing the main characteristics of the system on the vertical axis and time on the horizontal one. Fig.1 represents the graphical representation of such a curve with some explanations [2]. This curve completes the models of evolution enabling the person interested in improving one of the existing systems to correctly appreciate the level of the chosen system and especially to answer a major question: "Ought one to solve a given problem and improve the technical system specified in it or present a new problem and

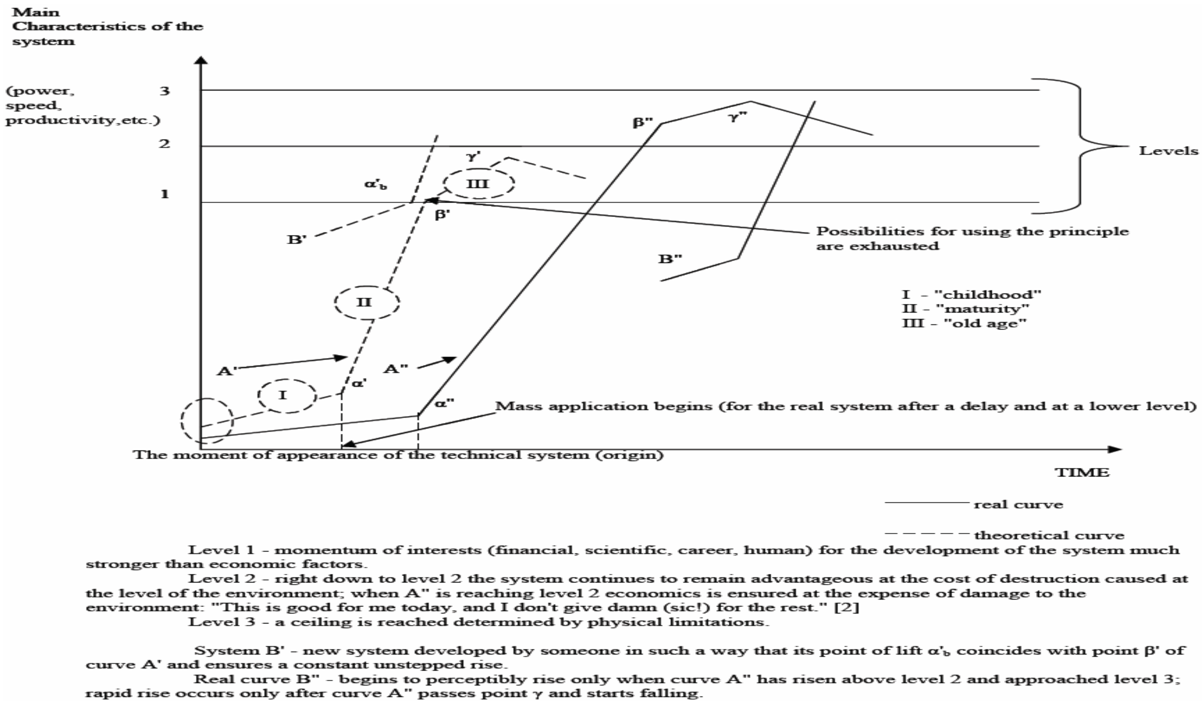

Fig. 1 The S-curve

arrive at something which is fundamentally new"[2]? The next quote justifies the approach made in this article with the purpose of having a different look on air navigation in terms of patterns of evolution of the technical systems, thus allowing for a better orientation of future developments. In an editorial published by Dave Grace, Executive Vice-President Technical IFATCA (International Federation of Air Traffic Controllers' Associations) in February 2007, it is said that: "When reading the various articles in the many aviation journals, one is often amazed at the diversity of automated solutions for the perceived problems in global air traffic management. Much of this information is based on good scientific logic and reason backed in some cases by empirical data. Others appear to be the extreme of where automation could end up 'no controllers – no pilots.' What will be certain is that automation is here for some and on its way for others. Among aviation professionals, including operational controllers, the idea of what constitutes automation and what it will mean to them will differ from individual, from unit, from country and from region. It will also be viewed in terms of the level of automation anticipated."

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