

## **THE CONSTRUCTING: ART, SCIENCE OR CRAFT?**

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### **1. Introduction – art in constructing**

When speaking of activity called the constructing we think over of what character this activity is. What features does it possess and which of them are inseparably related to it. Such a reflection is not only of investigating character following human curiosity but also has practical meaning for those who create future engineers through teaching the constructing. These considerations have a subjective character and result from author's speculations that have appeared for the years of his professional, scientific and didactic activity.

I mention three of the features, namely art, science and craft. I think that they all inseparably contribute to the activity called the constructing.

The constructing means creating in a creator's mind an abstract image of a certain material subject. In virtue of my own interests this subject I imagine as a machine, but the considerations are to be of a more general character. The creating of the abstracts itself is an act of the art, and even that is why the elements of the art build foundations of the constructing. Obviously, not every abstract can be regarded as the art. First of all it should include elements of novelty, be a creature that has not appeared before. Then it should make an impression on the observer. These features, indispensable in the creating, also

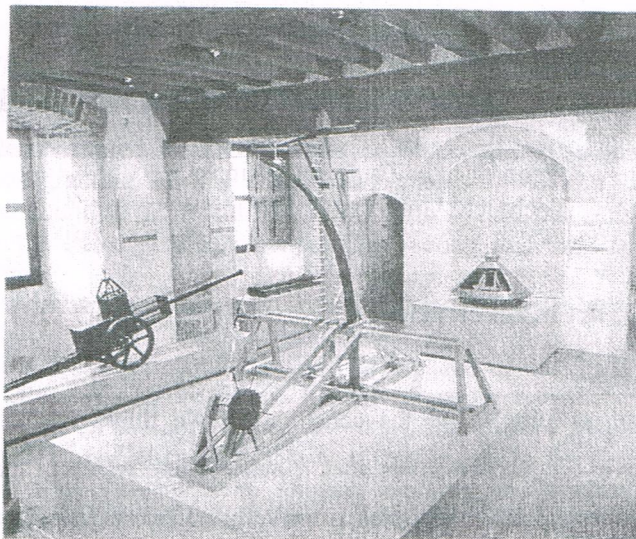


Fig. 1. Models of machines designed by Leonardo da Vinci exposed at the Clos – Luce castle (Ambois, France). Source: leaflet

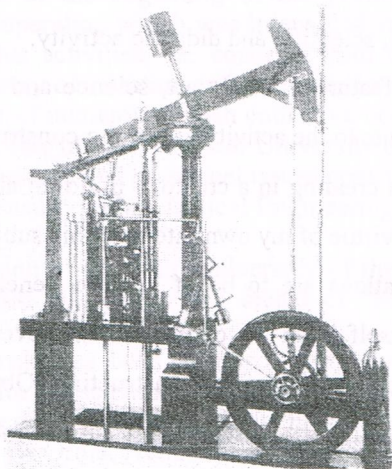


Fig. 2. Steam machine by J. Watt (model 1790). Source: [3], p. 156

occur in the constructing. The new, original technical creature, can bring impressions comparable to these provoked by a work of art.

These observations rest in the dawn of origination of conscious opinions on technical creation that appeared during extremely important for the art, science and technique age of Renaissance. That was when the term engineer came into being. The term comes from the Latin word "ingenium" and refers to mind's illumination leading to an original idea. Those were the times when profession of the engineer was associated with artistic activity. This epoch overflow with men of genius matching artistic creation with scientific and technical activity. Among the one finds Mariano di Jacopo (called Tacola 1382-1453), the author of "De ingeniis" and "De Machina". The other talented artist-engineer was Filip Brunelleschi (1377-1466), famous for building the cathedral dome in Florence. The most eminent representative of the artistic-engineer society was Leonardo da Vinci (1452-1519). He left enormity of projects which saw their realisation after years (Fig.1).

The concept of the art is hard to be defined. opinions on that have been continuously evolving. As the element of the art I mention the element of creation which indispensably must be related to creating works of art. Another feature is making suitable impression on the observer. Such an artistic experience, brought about by admiration of beauty of the work of art, is treated as important attribute of the art. The works created through technical activity can also provoke artistic impressions classified as the beauty. One can only mention the commonly admired structures, e.g. cathedral domes, particularly in Florence and St. Peter's in Rome. Great impression makes the Eiffel Tower as well. Some ships, especially sailing-ships, and some aeroplanes, cars, steam locomotives are also said to be beauty. It is to be emphasised that technical subject inspire artists, in particular painters. How often we can look at the



pictures presenting sailing ships, the technical creatures, in contact with the sea, the nature.

## **2. Science in the constructing**

The relationship between science and the constructing can be seen in an obvious way. It is known that each material subject realising given functions behaves in accordance with the laws of nature being described by science. Correlation between science and the constructing resembles a system with feedback. Sometimes scientific description precedes the structure. Science represents laws, and models which do not exist in reality but afterwards they see the process of their material realisation which is the constructing. Sometimes the structure appears before its scientific description. It appears due to designer's intuition supported by his practical experience. It happens that the existing technical subject is theoretically examined and this, not so rarely, contributes to development of scientific knowledge, and often becomes an impulse for creation of new branch of science. For example the constructing and manufacturing of steam machines distinctly left behind knowledge of thermal cycles. First trials of building steam machines go back to 1696 (D. Papin, T. Sawery). In 1755 already works the atmospheric steam engine (T. Newcomen, J. Cawley). James Watt starts constructing in 1763 the pressure steam engine (Fig. 2). At the end of the 18th and at the beginning of the 19th century work quite a large number of steam machines. Not before 1824 appears the first theory of the thermal cycle (N.L.S. Carnot) The thermal cycle of the steam engine becomes explained by V.J. Rankin in 1850. This is one and half century after the first steam engine began to work.



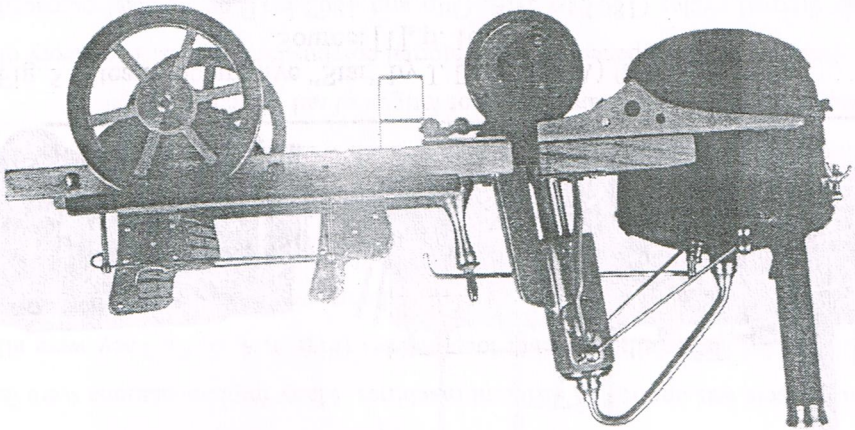


Fig. 3. Steam carriage by N. Cunot (France 1769). Source: [1], p. 3

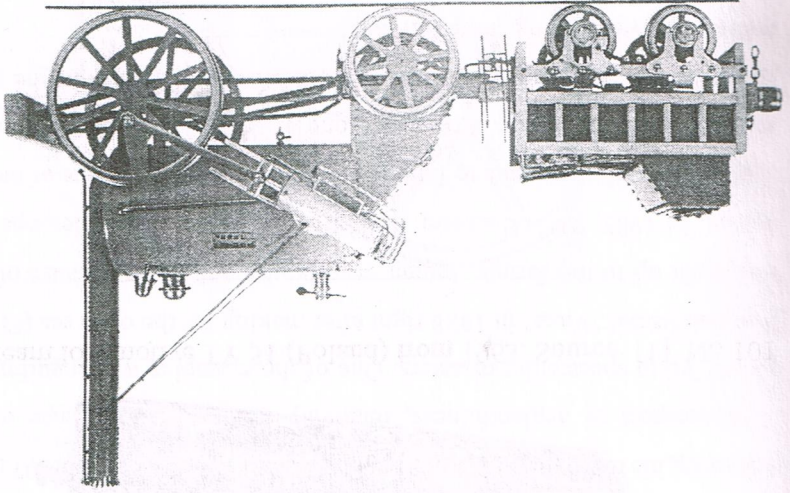


Fig. 4. Steam locomotive "Rocket" by Stephenson from 1829. Source: [1], p. 9

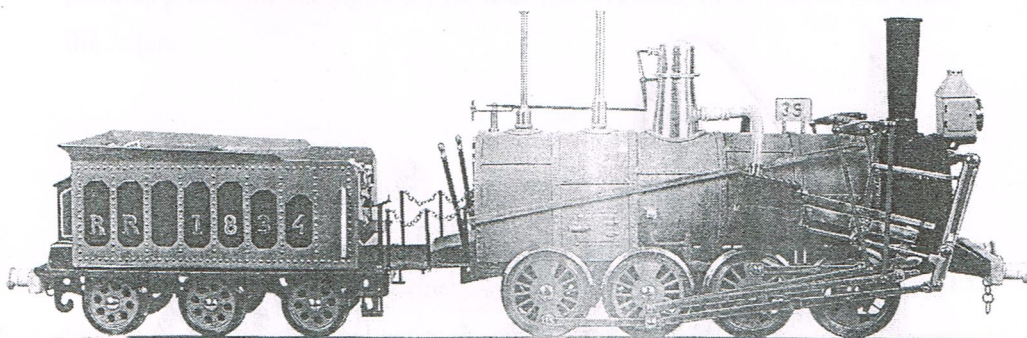


Fig. 5. Steam locomotive "Star" by J. Drips (USA) from 1834.  
Source: [1], p. 16

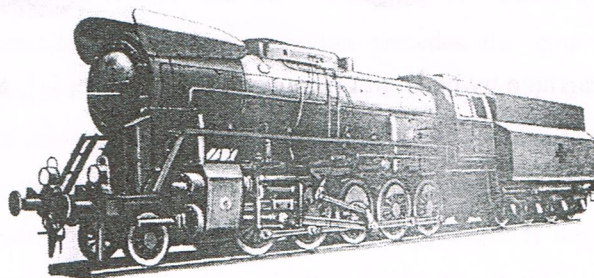


Fig. 6. Steam locomotive TY 51 (Poland) from 1963. Source: [1], No 101

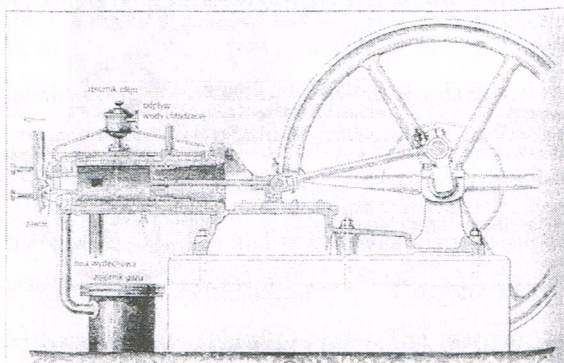


Fig. 7. Internal combustion engine by Otto (1876). Source: [3], p. 296



The same story goes with the theory of mechanisms. A variety of mechanisms was applied to different machines. Many implementations were in e.g. vehicles, especially in steam locomotives (Figs 3, 4, 5, 6). They were all used long before the development of the theory which appeared in the 19th century, except from individual solutions, sometimes much older.

The origin of science related to strength of materials resulted from damages observed in axles used in vehicles. This branch was initiated by Wöhler on the grounds of multi-years examinations of fatigue of rail wheelset axles.

Another thing happened with the internal combustion engines. The theory of their thermal cycles (1867 by N.A. Otto and 1862 by B.de Rochas) outpaced constructing spark ignition engines (N.A. Otto, 1876), see Fig. 7. A very clear case of leaving behind the constructing by science is the case of compression-ignition engine. Researcher R. Diesel developed the theory of thermal cycle following his name in 1892, and successfully built the engine in 1897 (Fig. 8).

Disrespect or neglectfulness, relatively not exact observance of laws of nature led to spectacular disasters. One of the examples was engulfment of the Swedish vessel "Vasa" in 1628 right after making for the open sea (Fig. 9). The ship built up to the former, bigger vessels was not stable because of too light ballast. In 1988, 91 m diameter steel structure of the radio telescope in Green Bank, USA, fell down due to fatigue cracks that occurred in one of the carrying elements of the structure. At present, one of the biggest auto makers enjoying great renown and having substantial research capabilities built the car which rolled over when taking sharp turnings.

Sometimes science is not prepared to describe the phenomena which were the causes of disasters. Among such a situation one can mention the phenomenon called flutter – the culprit of many aircraft disasters and spectacular collapse of the Tacoma Narrows bridge in 1940. The disaster resulting from underestimation of laws of mechanics happened during general



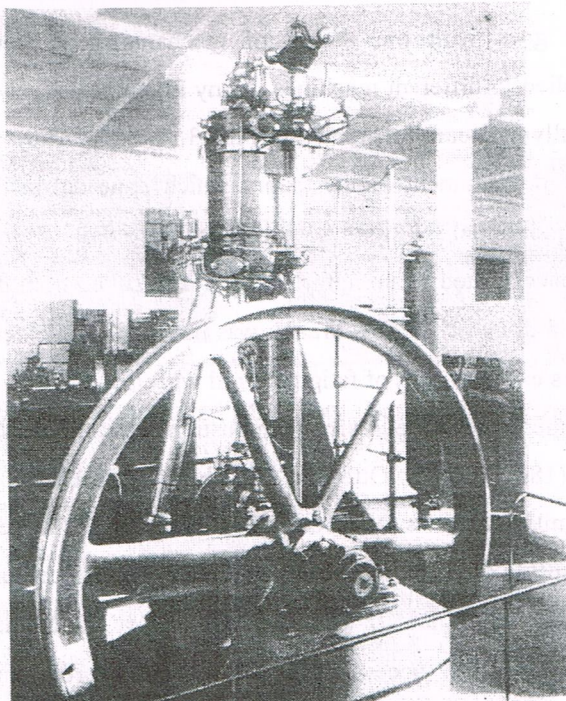


Fig. 8. Internal combustion engine by Diesel. Source: [3], p. 99

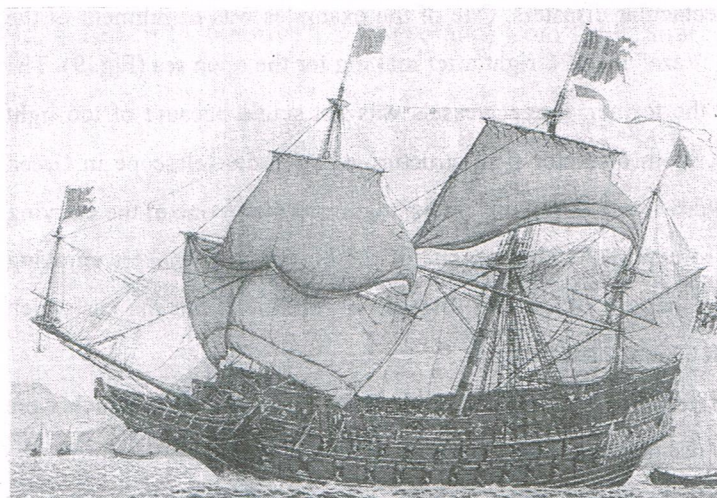


Fig. 9. Ship "Vaza" (1628). Source: leaflet

overhaul of the highest in the world aerial mast in Konstantynów. Underestimation of fatigue stress appearing in elements of fuselage was the cause of a series of aircraft disasters, e.g. of COMET de Havilland.

### **3. Craft in the constructing**

Element of craft in the constructing ensues from the fact that no creator can work in a blank and create anything from the very beginning. The creator has to know the fundamentals of his profession. The fundamentals include knowledge of manufacturing measures available at the given moment, of materials which can be applied together with their properties. He has to be aware of scientific grounds ruling the process of realisation of his work and enabling obtaining the product satisfying imposed requirements. Naturally, knowledge of existing patents, right and regulations, costs, market demand is necessary. This element of craft is often dominant in the process of constructing. Designer make easier their activity by transcribing the existing knowledge. The most characteristic are technical hand-books like "Taschenbuch für Maschinenbau" by H. Debbel readily used by generations of engineers. With the help of such a guide one can create the product up to the contemporary standards.

Let us consider a simple assembly constituting self-lubricating journal bearing (Figs 10, 11). The first constructor, or constructors, undoubtedly brought elements of creation to the work. Laws of science are obeyed in relation to processes of lubrication and generation of the oil film. They should also be taken into account when deciding about shape of supports. The elements of craft lie in incorporation of manufacturing techniques, choosing connecting and supporting elements, etc. The journal bearing has been applied to rotating machinery for years and still appears in its original shape or slightly modified,



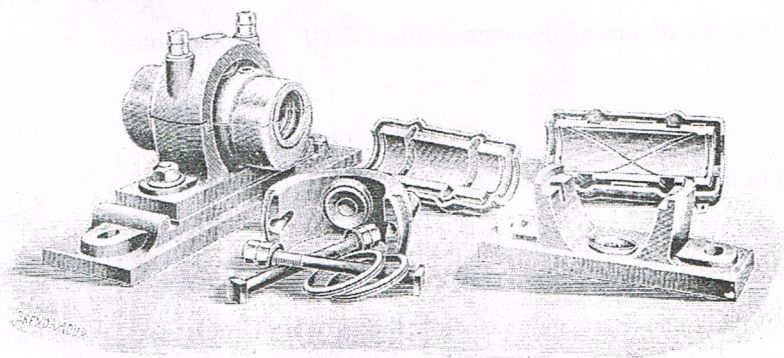


Fig. 10. Self – lubricating journal bearing. Source: [5]

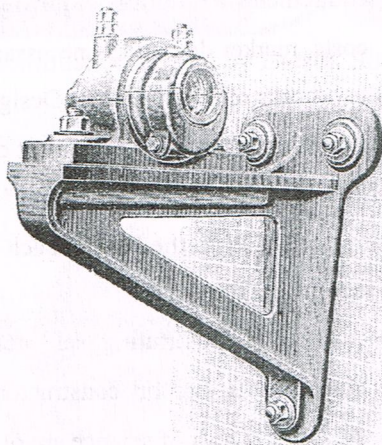


Fig. 11. Self – lubricating journal bearing in wall bracket. Source: [5]



thus cannot be treated as an anachronism. The enclosed figures (Figs 10, 11) were taken from the famous firm J. John in Łódź (1902)

#### **4. Progress in development of structures.**

While observing development of structures we can see the time periods when the construction of a given product (machine) does not undergo permanent changes. Usually, it is being only slightly improved. This can be regarded as the element of craft.

Quite often and quite quickly there appears a novel construction qualitatively different from the other ones. A rapid progress in development of structures takes then place. Obviously, not every innovatory construction contributes to such a progress. There also occur constructions very unfortunate. Sometimes, from the point of view of structural solution, the successful creatures scarcely find practical applications because of other reasons.

Appearance of novel, distinguishing from all the other contemporary existing structures, is due to talented constructors who match the elements of art, science and craft in their activity. The history knows such inventors. For example it mentions James Watt and his steam engine the construction of which was qualitatively different from other structures. The novelty consisted in the principle of the working, i.e. way of converting the steam pressure into mechanical energy, but also was related to solving of accompanying problems such as transformation of the piston translatory into wheel rotary motion, control, and making use of the materials and technological capabilities in a suitable way. Shaped by Watt structural form of the steam engine preserved for years with only slight improving modifications. The machine satisfied transport and industrial demands, and quickly became widespread.

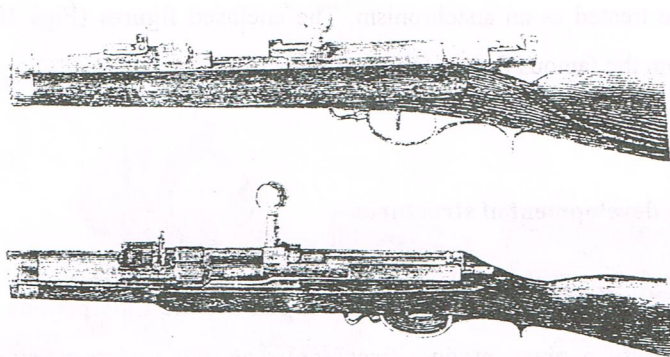


Fig. 12. Pellet rifle by N. von Dreyse from 1828. Source: [3], p. 201

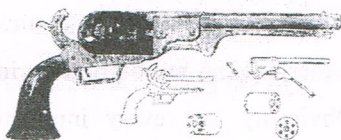


Fig. 13. Revolver by S. Colt (USA) from 1845. Source: [3], p. 229



Fig. 14. Revolver by S. Colt (USA) and Webbley (GB) from the I World War. Source: [2], p. 7



Similar role played steam locomotive by G. Stephenson. He was developing its construction from 1814 up to 1848. The steam locomotives brought solution to problem of connecting steam boiler with the engine, and to elements of transmission system. For years the construction of steam locomotives was the model of progressive structure widely followed. In constructional solution to muzzle loaded single-loader rifles the jump progress took place by inventing breech loading. The new construction, on the base of which further improved versions were produced, was the work by N. von Dreyse (Germany, 1828), see Fig. 12. It was the rifle with pellet causing detonator explosion in the cartridge chamber. This idea was also introduced to pistols and developed in repeating guns. Such a turning-point in design of guns was the construction of revolver introduced by S. Colt in 1842 (Fig. 13). The principle of rotary motion of the revolver drum driven by firing mechanism has been applied in guns produced up to present and the construction itself, after a series of modifications (at the end of the 19th century) remained virtually unchanged (Figs 14, 15). Analogous features of the turning-jump in arms construction had repeating pistol the first version of which was worked out by P. Mauser in 1896, and developed in 1902. This pistol was equipped with drum magazine containing 10 cartridges (Figs 16, 17). In the field of self-repeating automatic guns the turning construction was the Kalashnikov rifle (1947). This construction has been used up to now and saw numerous imitations. A few years before appeared German machine gun MG42 (1942). This construction initiated production of universal machine guns replacing old versions of automatic light, medium and heavy machine guns (RKM, LKM, CKM).

Great progress, owing to concentration of creative activities employing science and craft, was made in the domain of construction of aeroplanes. It is only to compare the aeroplane built by O. and W. Wright brothers (Fig. 18), which flew 36 meters, to present strategic and passenger aircrafts (Figs 19, 20)





Fig. 15. Present revolver (Roger New Model 0.32 Magnum).

Source: [2], p. 70

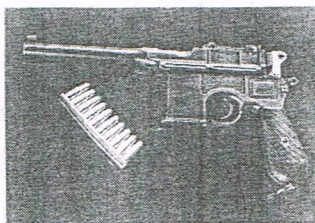


Fig. 16. Pistol C96 by Mauser (Germany) from 1896. Source: [2], p. 10

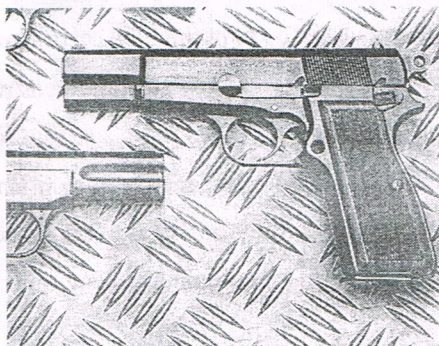


Fig. 17. Present pistol GP 35 (Belgium). Source: [2], p. 12

to see impressive quality jump that took place within this century. Such an achievement cannot be assigned to a single inventor or even a single research centre – it is also hard to mention all the creators who contributed to this progress.

Construction of airframes based on beam and truss structures evolved to thin-walled shells. Tremendous changes were made in construction of undercarriages, in the way of engines mountings and in steering.

The coupling between the constructing and science reached a high degree of engagement. Laboratories, scientific institutes were founded to examine aircrafts. The knowledge related to aerodynamics became advanced and enabled obtaining new wings profiles together with possibility of changing their aerodynamic properties by adding controlling surfaces and landing flaps. A great progress was observed in the studies on strength of structures, especially with regard to fatigue and fracture. These investigations and experiments were the main cause of rapid development of aerodynamics as scientific branch. Similarly happened with problems of flight dynamics and stability. Building of aircrafts made an effect on introducing new structural materials, e.g. light metals, high-strength steels, composites, titanium, etc. Favourable circumstances, high demand for strategic aircrafts (unfortunately because of (numerous wars) were conducive to such a situation.

Sometimes creative intentions of a constructor outpace the epoch. The construction cannot be used in given conditions and must yield to less ambitious solutions. The example of such a case was building by J.K. Brunel the ship "Great Eastern" in 1860 (Fig. 21). The ship was six times longer than vessels floating at present. It had 18915 gross register tonnage whereas the previously built "Great Britain" had 3270 BRT. Its length measured 211 meters. It could take 4000 passengers. Only after 40 years even greater ship, called "Lusitania", was built. The ship realised all novelties of the marine engineering.



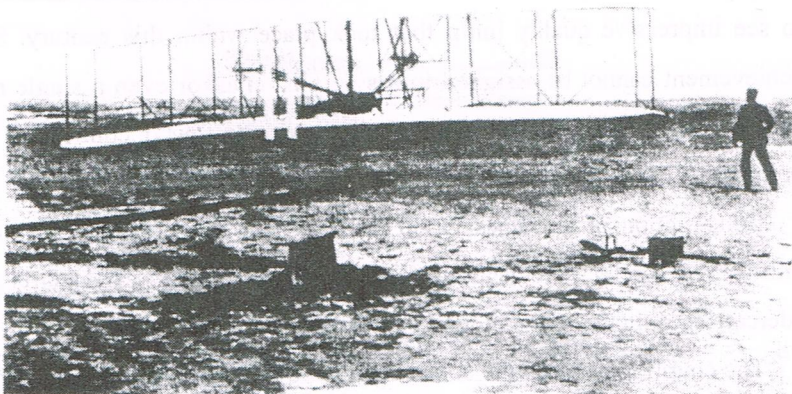


Fig. 18. Areoplane by Write brothers (USA) from 1903. Source: [3], p. 365



Fig. 19. Fighter MIG29.  
Source [5], p. 719



Fig. 20. Passenger aircraft A 330.  
Source: [5], p. 719

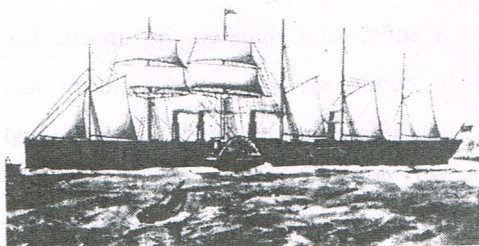


Fig. 21. "Great Eastern". Source: [4], p. 32



It was made of steel, had double bottom and watertight bulkheads, was equipped apart from sails with two types of steam-powered engines – one with side water wheels, the other with screw propeller. The size of the ship caused problems already as while launching. The vessel jammed and waited 3 months until gracious fortune brought the flood tide and the ship launched itself. The vessel was never used duly. It brought losses and mainly helped during laying the oceanic cable through Atlantic to which it had not been intended. Broken after 31 years yielded first profit to the last owner from a sale of part materials by auction.

An example of the construction which outpaced the epoch, in closer to the present times, was building Russian supersonic passenger aircraft TU 144 in 1969 and French-British "Concorde" (1967). Flights of TU 144 were suspended in 1974. Then immediately "Concorde" came into exploitation. The aircraft flew at twice of the sound speed (Mach 2) and cross the Atlantic in 3.5 hours. It could not yet withstand economic competition with slower passenger aircrafts. Finally its production was stopped.

When speaking of works of art one often underlines the names of the artists who have gone down to posterity. In engineering such a situation takes place as well. Hence we remember the names like J. Watt – creator of the steam engine, Wright brothers – creators of the first aeroplane, Otto and Diesel – inventors of the internal combustion engines with spark and compression ignition, Stephenson – the first to build steam locomotive, Benz, Daimler and Maybach – main contributors to the work on earliest cars, etc. But quite often names of constructors are not exposed. This results from the fact that the works of technique became effects of collective endeavours. The works are more and more often associated with names of the producers. Names of the true creators inventing constructions of genius become less and less known, sometimes do not come into light at all. This phenomenon is not new. The name of the famous

Eiffel Tower refers to the owner's name of the firm which built the tower. Only some few know that the constructor and creator of the tower was M. Koechlin. Quite often names fell into oblivion because of more fortunate or better advertised, relatively more widespread products created by next constructors. So did happen with those who before Wright brothers built aeroplanes which made their short flights.

### **5. The constructing enhanced by computers – computer aided design**

In relation to rapid development of methods enhancing the constructing by computers one can rise the question whether these methods do not limit the creative role of the constructor. At first choke caused by computer capabilities many said about automatic design expecting that computer would choose the optimum solution without designer's participation. But shortly it occurred that that this was impossible. Each structure has to satisfy many, often contradictory, conditions. Fulfilment of each condition leads to tasks of multi-objective optimisation with the optimisation criteria being hard to reconcile. The designer has two possibilities. He can assume many criteria and look for the way of their fulfilment or he can quit optimisation of some features by fixing their numerical representatives as extreme values and thus generate a system of constraints. Even in such a procedure the designer is free to decide. His system of constraints has strong effect on the structure. On the other hand, by realising the optimisation procedure with taking into account a larger number of criteria, even with the system of constraints, one will never obtain one and the only solution. Designer gets a set of optimum solutions and has to choose one of them. It is not important whether he decides a priori by imposing a single collective objective function with corresponding weights or a posteriori by



choosing single solution from the obtained set of optimum solutions or choosing the optimum one through a dialogue with computer.

The element of creation in the constructing rests in creating new constructional forms and it does not consist in effects brought about by computer procedures. This is domain of the constructor. Computer plays only supporting role. It enables designer to check fastly what effect on the construction quality would have his proposed modification (form of the structure). Therefore, introduction of the computer aided design does not change qualitatively the character of the constructing. Naturally, it remarkably enhances this process. It is especially expressed in giving facilities for making use of scientific elements. Computers also inform of existing solutions, materials, standards, technologies, of all what is understood to be the craft. The constructing, like any other creative activity, consists largely in making decisions from a big set of different possibilities. Computer aided design enables a quick overview of possible variants, and thus make the deciding easier. It should be also said that great possibilities are held in the suitable assortment of the constraints. Repeating of certain values of such constraints leads often to disregarding of their role. This can even set back the progress in appearance of new constructional forms. The designer has to sometimes weaken the imposed constraints, i.e. apparently worsen the quality of a structure, in order to introduce a new form being preponderant over the existing and widely used constructions. For example, the operating for years heavy machines like excavators or cranes had their working systems driven by transmission ropes and were characterised by excellent efficiency. In order to introduce the new solution based on hydraulic transmission exposing other advantageous features the designers were forced to give up high efficiency and let it drop.

## **6. Teaching the constructing**

Character of activity related to the constructing and the aspects appearing in it should be reflected when teaching students in faculties associated with design. Obvious is the necessity of appropriate scientific preparation of teachers. In the case of machine design this preparation must include acquired knowledge in mathematics, physics, mechanics, strength of materials, thermodynamics, fluid mechanics. During university studies these subjects precede courses of design. The key subject related to design is Fundamentals of Machine Design being in fact a passage from the exact sciences to specialistic subjects dedicated to knowledge of structural design of different machines. In teaching Fundamentals of Machine Design the essential role plays the courses of design fundamentals but also the lectures from which the students can learn how to make use of the exact sciences in the design practice. There exist every reasons for introducing the ways of using elements of science to the entire course of teaching the constructing. Much harder, however, is to train the creativity. Ability to act in a creative manner depends mainly on aptitude of the future engineer. Non the less the aptitude can be improved. This requires suitable presentation of known good constructions, their historical development, needs to portray characters of famous constructors. When studying design solutions the teachers should emphasise the possibility of making own variants by the students while working at a given construction.

Mastering the elements of craft is continuous process initiated at technical universities by conveying to the students knowledge of materials, standards, regulations, manufacturing technologies, typical elements of structures.

One can expect that technical universities will prepare the student capable of getting the needed information.



### Sources of figures

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