Cezary SZCZEPAŃSKI

MECHATRONICS SYSTEMS DESIGNER EDUCATION

Streszczenie

In the paper the author's remarks on mechatronic system designer type of education and its compatibility to industry practise has been presented. The university graduates adaptability to the industry conditions on the examples of graduates from different faculties of universities and universities of technology is analysed. The practical conclusions on the usefulness of graduates of different types of universities for the mechatronic systems designing companies have been presented.

INTRODUCTION

Mechatronics systems and machines are becoming more and more widespread through the all technology disciplines. All newly designed and modernised machines receive their own computer systems, digitally controlling operation of other kinds of on-board hardware systems, like hydraulic, pneumatic, mechanic. Also the human operator – machine interface is based on the electronic displays rather than electro-mechanical indicators, like in the past.

One of the devices, which are the very good example of mechatronic systems, are the flight simulators. They are systems used for training the civil and military pilots in standard and abnormal piloting situations, i.e. proper performing the flight procedures in all possible states of the flight. Those abnormal situations could be connected with the following reasons:

- severe weather conditions, influencing substantially the flight conditions,
- malfunctions of on-board systems and devices, starting from simple damages of an indicator, ending with the breaking down of the engine,
- damages of an airframe and some on-board systems caused by the enemy fire (for military pilots training programs).

The cockpit of the simulator is a detail replica of the real aircraft cockpit, with all the indicators, gauges, switches and control levers looking and acting like real ones. They should also be used and controlled by the pilots like their real originals. Fulfilment of all those requirements is strictly controlled and certified by the proper Civil Aviation Authorities according to international standards. Flight simulators used for civil pilots training are re-certified every year.

From that short description one can easily see that the flight simulators are very complicated devices, consisting of hardware: mechanical, electrical, electronic, fine mechanical, optical, high power hydraulic elements and subsystems. They are driven and controlled by the computers dedicated for: modelling, computer graphics generation and presentation, controlling and data transmission, with installed real time software. All those areas need highly educated and experienced specialists for their design. The flight simulators are never made in a serial manufacturing mode. They are at least adjusted into individual requirements of the client from the standard model or even designed from scratch. That is the reason, why in that industry there is requirement of the engineers designers able to perform the specification/requirement analysis, design and develop of the device and/or its modules including their hardware and software.

1. FORMULATION OF THE PROBLEM

It looks obvious that the teaching of the hardware and software engineers combining all above listed specialised knowledge would be very difficult, practically impossible during the standard period of university education. So, very natural question is which type of university is able to prepare the best designers and developers of such mechatronic system like flight simulator is? That question is including the question of compatibility of curricula at two types of universities: general sciences and engineering ones. The following analysis has been done for the Bachelor and next Master of Science also Bachelor and next Master of Art degrees courses provided by the Polish universities of technology and universities within the five years (10 semesters).

All the remarks and conclusions mentioned in that paper have been done on the personal experience of the author. He has in total 29 years of experience as a Professor of the Warsaw University of Technology, Military University of Technology and Wroclaw University of Technology. In 1985 he initiated the „Flight Simulators" lecture introducing then simulator technology area to the University education scope. On the other side for 13 years he was the President and Director General of the ETC-PZL Aerospace Industries – the company which designs and produces simulators and training devices. Those two in parallel performed activities allow for concluding some general remarks.

Also it should be said here that the industrial requirements against the designers and developers were formulated on the base of high-end simulator (see Fig.1) developing company having about 100 employees. That size companies are typical in the simulator industry, along with four big world leaders and plenty of smaller ones.

Fig. 1. *W3WA "Sokół" helicopter full mission/flight simulator [ETC-PZL Aerospace Industries]*

Such small size company production profile shows the necessity of supporting the whole life cycle of the product - simulator. Beginning from the requirement analysis and discussion, through all the stages of designing, by manufacturing and integrating the elements and subsystems, mounting complete simulator at the user facility, up to servicing it during guarantee period, and also providing its post guarantee service and upgrading.

Taking into consideration all above company expectations we can formulate the ideal graduate abilities. He should be specialised or at least well oriented in his area of interest, have some general knowledge on simulator technology, and should have abilities of doing:

- theoretical analysis of physical processes to be simulated,
- synthesis made on that base resulting with mathematical models fulfilling some specific requirements, like: proper accuracy and possibility of its real time performance,
- practical implementation of those analysis and synthesis results (models) into the real device in the form of designed hardware (HW) or software (SW),
- testing that real device (HW or SW) within the testing environment,
- analysis of his work results and on that base making decisions on its development.

It is easy to see that tasks like those above usually are performed by highly educated and experienced designers/developers. From the freshly graduated we can expect a good education but almost no experience, particularly as broad as is needed.

It means that the ideal university graduate, from the company point of view, should have at least good theoretical background and some practical experience in his specialisation area. That is commonly agreed not only among the mechatronic area companies..

From the author's experience comes out, that additionally some soft abilities are very important. They are: ability of team work and presenting „economical" attitude towards the project. Those two last soft characteristics are seldom trained at universities, although they are crucial for any real industry activity. In such cases company needs to train their newcomers both in team work and proper counting of the costs in their projects.

Through the last 8 years of author's activity in the company a little more than 40 university graduates have been employed. Analysis in the paper will be done separately for hardware designers and software developers, and for the last ones graduated from universities and universities of technology. That way of differentiating came from author's experience with process of adaptation to industrial conditions of different kind of universities graduates, taken by the company. Within each of those three groups we can find some common problems and characteristics, allowing for implementing such division of them.

2. HARDWARE ENGINEERS

All the hardware design engineers working at the flight simulator projects came from the different universities of technology. They were graduated from following university of technology faculties: mechanics, fine mechanics, mechatronics, optics, automatics and control, electrics, electronics, aeronautics. They are specialists in the following disciplines: machinery building, aeronautics, electrical power engineering, computer systems, lighting, electronics, real time control systems, power hydraulics, optics, theoretical and applied mechanics, precision mechanisms building, control theory.

During their work at the company they design hardware modules of simulators, like: motion systems (see Fig.2), cockpit and cabin functioning replicas, visualisation systems hardware, instructor stand, control force loading systems, power supply systems, real time transmission and control subsystems.

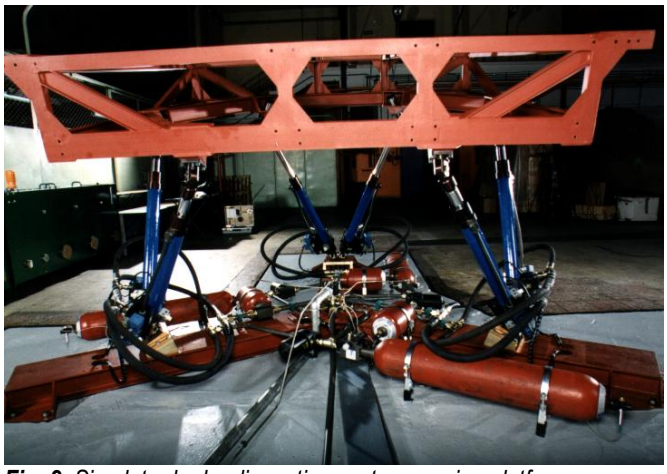

Fig. 2. *Simulator hydraulic motion system moving platform*

The designing process is preceded by specification and requirements analysis and followed by the purchase orders for the off-the-shelf elements and subsystems. If those elements are not available or they are not compatible with other designed elements or their cost is not acceptable from the project budget point of view, the leading designer makes the decision of manufacturing them at company workshop and/or specialised factories. All described here phases are performed by engineers and graduates among them. After receiving those ready elements by the company, next the graduated hardware engineers integrate and/or supervise integration of the elements and subsystems into the simulator systems. They always take part in the final stage of integration of the simulator and also they are active in all stages of testing of the completed device. From the company point of view it is the very important part of the professional on job training for those graduates. Some of them take part in moving of the simulator to the final user facility, where the whole simulator needs to be integrated, tested and passed over to the client. After successful passing by each of the

hardware engineer of such whole way of simulator development and testing, we can say that the former graduates became sufficiently experienced engineers ready for independent work at the next project, as the full members of the team. It takes at least two years.

The typical situation is that some graduates have not enough predisposition to fulfil duties in some of the stages of simulator production process. That is not unexpected, as nobody could expect that each one graduate would be able to do all those kind of jobs with the same efficiency. It is necessary to check their abilities and preferences as soon as possible after their arrival to the company, and to decide how to use them effectively in the designing and development process. It means that future career of engineer depends on his abilities and effectiveness. Some of them become team leaders, some R&D workers or team members and some could be used only for typical, repeatable functions like manufacturing supervising.

Typical checking time of individual abilities takes three to six months. During that period we should check as much abilities as possible. If somebody is thought to be useful for company and he accepts conditions of work after that period he starts normal career as described above.

We must say here that our practice has shown the importance of that initial period. The candidates must be checked and supervised carefully. But our experience has also shown that a typical university of technology graduate, who has passed lectures on simulators and/or done semester projects or master thesis in that area, is well prepared for work at the simulator company. Our university of technology curricula are composed to be sufficiently compatible to mechatronic industry requirements and expectations. But that thesis is true only for good and very good students. The graduates with final note less than good are very seldom able to fulfil the requirements expectations industry has of them.

3. SOFTWARE ENGINEERS

Software engineers have been coming from the two types of schools: universities and universities of technology. The university graduates were mostly from mathematics and computer science departments. The university of technology graduates were from computer science and electronics (software) departments and from theoretically minded students from other departments, like aviation, applied mechanics, technical physics.

At the beginning of our considerations on software engineers we should analyse the type of works done by them at the simulator building company during the flight simulator development.

The very principal question is: what kind of software should be developed for that simulator? There are the following types of software necessary for the simulator, according to the internationally accepted standards and simulator technology practise:

1. modelling:
– the dynamics of motion (flight and on ground behaviour),
– work of on-board installations in normal and abnormal conditions,
– environment: weather and actions of other participants of airspace influencing simulated object;
2. controlling in real time mode:
– the motion system moving platform (see Fig.2),
– control forces loading generators,
– cockpit indicators, gauges, switches and levers control unit,
– visualisation presentation system,
– simulator on-line monitoring system;
3. modelling and generating of all the sounds which could be heard in the cockpit,
4. computer image generator (real time computer graphics) creating the 3D world surrounding and cooperating with the simulated aircraft,
5. data transmissions, connecting simulator modules, co-ordinating their work, transferring data between them and allowing for controlling and supervising by the instructor the whole exercise performed on the simulator,
6. for the instructor stand,
7. for the off-line analysis of performed exercise and individual student training data storage.

There is no doubt that it is impossible to have one specialist for development of every kind of software listed above. The following question arises: if graduates from different kind of university or university of technology departments could be more able to perform different tasks, i.e. to develop different part of the software?

After years of trials, we can say, that it is true. Some faculties curricula prepare their graduates better for a few types of work to be performed. In the following part we will discuss such cases. The graduates from aviation department of university of technology with some knowledge of programming could be preferred for creating the mathematical models and algorithms and also writing the source code of dynamics of flight of: simulated object or flying objects from environment module. The graduates from computer science departments, from both types of universities, specialised in computer graphics are preferred for designing and programming visual data bases and the software for computer image generator creating the real time 3D world. For real time controlling of the hardware elements of mechatronic system the graduates from universities of technology appeared to be preferred performers.

Such examples show experience achieved in a small/medium High Tech company, where is no big formal structure of software engineers, i.e. systems analyst, system designers, algorithm designers and programmers grouped in the separate divisions. There were software developers dedicated to individual project – building a simulator. Next they were named responsible for a certain task – development of the defined part of the SW. Our experience shows, that almost every member of the software development team performs duties of a few from above positions. That is caused by individual tasks structure, which usually gets the form of problems or individually performed modules of software.

For example, one software developer who is responsible for the model of flight has in his responsibility the following duties:

– creating or adopting the mathematical model of spatial movement of simulated aeroplane during all the stages of flight, in normal and abnormal conditions. That is not trivial task and in fact that person must co-operate with external R&D centres and aeroplane designing office with collecting data, and analysing them. On that base he builds the mathematical model of aeroplane flight. He is also responsible for verification of that model by a team supporting its formulation;
– next step is assuring the real time action of developed mathematical model by a hardware platform used in a simulator;
– providing the accuracy and effectiveness of the model. It means that he should assure the necessary frequency of calculating of the model and its proper accuracy, in simulated normal and abnormal conditions of flight. This is also connected with proper choice of numerical methods of solving the systems of differential stiff equations and algebraic equations or with modifications of standard library procedures solving them;
– assuring the correct communication and data transfer of flight dynamics model with other models used in a simulator;
– writing the software coding the formulated model;

- providing the correct communication of that software with other software modules;
- tuning the developed model during the final trials of the whole simulator, during the company tests and final acceptance tests with the help of test pilots;
- checking the model after moving the simulator to the user facility;
- maintaining and servicing that model during the simulator exploitation period.

As one can easily see, some part tasks performed by that software engineer are of different types. They belong not only to any kind of software engineer duties but also to R&D engineer, team leader or project manager duties. In fact, at a mechatronic systems developing company software team engineer must be of a very universal type. He must be able to perform independently and reliably different tasks. Also must closely co-operate with the other team members at least in exchanging the information necessary for successful performance of the whole task. So in one person we would like to combine a soloist and a choir member playing both roles at an acceptable professional level.

It is not easy to find people who can perform all those duties and kinds of work sufficiently well. Particularly it is difficult to foresee if a newly employed university graduate can do all those works. It is really difficult but not hopeless. Having some experience and introducing those new employees into company activity properly, after six months period we can estimate his abilities.

For the above listed characteristics and tasks the graduates from universities of technology are more complementary than university graduates. During my work in that company I realised, that graduates of universities (department of mathematics, computer science) as general are less prepared for work at industry in small/medium High Tech companies than their colleges from universities of technology's same type departments. Even graduates from physics department of universities are better prepared or are more adaptive to the new conditions of activity than from computer science ones. That opinion has been established on the probe of the 10 graduates from computer science departments of universities.

In my opinion the reason of that situation is that computer science and mathematics graduates from universities during their studies have much less contacts with real life problems than the others. They are taught in a very abstractive way and often they are trained in solving artificial problems created only for didactic purposes. Those problems were too simple and artificial to be compatible enough with the real life. In effect the background of those students is unrealistic. Very often they are fluent in solving some sophisticated but artificial problems, which have no references to real life. For example, they are fluent in proving some mathematical formulas without referencing them to the real life phenomena, which could be described or solved with the use of such formulas. If they meet a more complicated situation in a more complicated environment then even a comparatively simple task becomes completely new and difficult. Saying background I mean the basic knowledge of discipline they took at the university. For example, the university of technology graduates of aviation department took basic knowledge of theoretical mechanics, thermodynamics, fluid mechanics, principles of machinery designing, automatics, control theory, mathematics, computer science, manufacturing methods, principles of management. This is a wide area of scientific disciplines allowing for smooth integrating information from them into good individual knowledge base, which could be very useful for mechatronic systems building purposes. It is much easier and quicker to upgrade their fluency in computer languages and coding techniques then to teach graduates of university computer science department the suitable basics of some natural sciences. That internal knowledge built on the basis of a few year university studies occurs to be very important factor simplifying the adaptation to industry conditions, and creating preferences for certain types of work.

Also the university computer science and mathematics faculties graduates have their background but it is more theoretical and artificial. They much easier can adapt themselves in virtual computer environment. Therefore they are more effective in designing and programming the software connected strictly with computer hardware, like transmission of data streams, creating data base structures. If we are at the face of any real life process, like hydraulic actuator control, they are much worse than university of technology or physics graduates. The last ones have more references in their background then the others, similar problems they met during their studies. Knowing it we can better program their career taking into consideration that aspect.

Let's return to our main topic of flight simulator designer as an example of mechatronic system designer. I shall try to indicate the best type of graduate for each kind of software developed for the flight simulator, according to my personal experience.

- For the modelling software - aviation department of university of technology graduates.
- For the real time controlling software - graduates from electronics and computer science departments of university of technology or mechanical/aviation faculty graduates.
- For the software modelling all sound effects - the electronics and computer science graduates of university of technology.
- For the software connected with computer image generator the most reliable are computer science graduates from university or university of technology.
- For data transmissions software the best developers are graduates from electronics or electrics departments of university of technology.
- For the off-line analysis software the most effective are graduates from aviation or physics departments of university of technology. But this kind of software is the least dependent on type of developer education.

The above statements do not mean that there were not individuals graduated from different universities or departments who performed above listed tasks properly. But "statistically" seeing the problem and analysing their effectiveness in other tasks performance I can say that the above list is correct, according to my personal experience.

In all the above kinds of software there are groups of tasks or independent tasks which could be performed by an individual person and also more complicated and/or bigger which need teams for performing them. With the smaller and simpler tasks it is simple to answer who should perform them, according to presented analysis. With the bigger and more complicated ones it is not so clear. Let's check it on the example of the software team for preparing data base for flight simulator visualisation system.

Usually it is a task for at least a few persons team. Who should be the member of that team? As it was mentioned before, that software belongs to a kind which could be performed the best by the computer science graduates of any type of university. So, should every member of the team be a university computer science graduate? Not necessary. Here we have the work for more types of departments graduates. The structure of the data base should reflects the information which it should contain. The kinds of information which should be covered by the data base is defined usually by aviation department graduate with co-operation of future simulator user, who is pilot instructor. But the data base type and structure is

usually designed by the computer science department graduate. Developing the tools for creating that data base or adapting the existing tools is done also by a computer science graduate. But those tools are used by different type of schools graduates, who have enough 3D imagination, are patient and have certain level of understanding of their task. In fact it is unnecessary to have all the members of that team with the university education. On that example we can easily see that in bigger or more complicated tasks there are works for different type of departments graduates. Building that team we must decide who of them will participate in the team through all the time and who will be a member only for a time being.

Generally, for the more complicated tasks, like computer image generator software, the above statements on the university graduates origin are valid for leaders of the team and its main members. That must be really understood. It is very important to have as a formal and informal leaders people whose knowledge is of that kind, which is preferred for the certain kinds of performed tasks.

As we are at the teams, we must also take into considerations the psychological and sociological aspects of team creation, including abilities of individual graduates for team work. But it is not a matter of that paper.

4. GENERAL REMARKS

Many words written above look like given truth, but they came out of the author's personal many year experience. In such a short paper it is impossible to prove all the above theses. Those from the readers who have similar experience may agree with author the other ones probably may not.

It is necessary to remember, that all remarks made in the paper were based on the group of about 40 university graduates starting their first job during the 8 year period. The simulator building company employs about 100 persons and acts in Poland. All the graduates taken into considerations were from the Polish universities and universities of technology.

Some problems with adaptation to industry conditions of graduates of universities computer science departments might have been caused by unique, in the Polish scale, specialisation and knowledge needed by a simulator company. That could create the situation, when freshly graduated students realised, that their knowledge is in minimum useful for the company requirements, at least at a first glance. But in fact we know it and we train all our personnel at the beginning of their work. Initial period of their work is devoted to introducing them into their work and also introducing them into our teams. That is being done mainly by the type of tasks dedicated for them at the beginning. Also they are starting with their future team members who take care about them at the beginning.

On the other side the simulation techniques are becoming more popular in research and designing. They started to be taught "the simulation" at the universities as the powerful tool. So some introduction and basic theory on that technology we can expect from all of the university graduates. It should simplify their adaptation to the real life of mechatronics industry.

CONCLUSIONS

Summarising the analysis we can conclude the following:

- the 'hardware' departments graduates of universities of technology are well prepared for the work at a mechatronic systems building company;
- the 'software' departments graduates of universities of technology are better prepared to work in the industry conditions then their colleges from university departments;
- the 'software' departments graduates from the universities of technology are better performers of tasks connected with 'real life' problems;
- the 'software' departments graduates from the universities are more effective at the tasks connected only with computer hardware and software problems;
- the most important reason of such conclusions, in the author's opinion, is the type of background knowledge which the graduates took from their universities.

KSZTAŁCENIE KONSTRUKTORÓW SYSTEMÓW MECHATRONICZNYCH

Streszczenie

W artykule przedstawiono uwagi na temat kształcenia uniwersyteckiego projektantów systemów mechatronicznych oraz ich przystawanie do wymagań przemysłu. Przeanalizowano przykłady absolwentów różnych wydziałów uniwersytetów i politechnik pod kątem przystosowywania się przez nich do pracy na konkretnym przykładzie firmy projektującej symulatory. Zaproponowano praktyczne wnioski dotyczące przydatności absolwentów niektórych wydziałów różnych typów uczelni do realizacji zadań w ramach projektowania systemu mechatronicznego.

Autor:
Szczepański Cezary - Politechnika Wrocławska, Katedra Inżynierii Kriogenicznej, Lotniczej i Procesowej
cezary.szczepanski@pwr.edu.pl