Practical application using the hexapod robot for interior inspection of a Boeing 737-300 aircraft fuel tank

Maria-Giorgiana GAINA*

*Corresponding author
"POLITEHNICA" University of Bucharest,
Doctoral School of Aerospace Engineering,
Polizu Street 1-7, sector 1, Bucharest 011061, Romania,
mariagiorgiana_gaina@yahoo.com

DOI: 10.13111/2066-8201.2021.13.2.7

Received: 20 January 2021/ Accepted: 04 March 2021/ Published: June 2021

Abstract: *This paper focuses on the dangers assoicated with the entry into aircraft fuel tank. The analysis will help to demonstrate that in the future a mobil robot will make this work easier for the human factor. There are number of advantages from this automation to make the job of the human factor easier and to work in a safe environment. The risk of contamination with harmful substances is reduced because we can put the robot to work. After detailed analysis of the working environment to which a mechanic is exposed in the aviation world, it has come to light that the introduction of a robot makes it minimal. I tried to analyze several types of mobile robots, and after this analysis I decided that the most suitable mobile robot is the hexapod.*

Key Words: *Identification, Control, Human factor, Aircraft, Fuel tank, Robots*

1. INTRODUCTION

The main purpose of the practical application was to be able to check whether the designed hexapod mobile robot can correctly fulfill the mission of entering, moving and capturing relevant images, through the inspection cameras inside the aircraft fuel tank.

The idea of using the robot is the result of assessing the risks that the human factor always encounters during the inspection of fuel tanks, which is an extremely toxic environment for human beings. The use of the hexapod robot could largely eliminate this, by substantially reducing the time required for personnel to enter the tank, which will only be done in special situations. For making this application the following stages were completed: analysis of the work environment and awareness of its risks, theoretical substantiation, conceptualization, implementation, verification and acceptance.

In order to carry out inspections inside the aircraft's fuel tank, certain rules must be strictly observed, from the moment of entering the tank until the completion of the inspection. Although the hexapod robot does not have a complex level of manipulation and control, its manipulation is possible with a computer or a smartphone, and can be improved and an example could be: placing cameras inside each leg of the robot helps to see better inside the fuel tank, as well as the installation of certain scan sensors, etc. My intention in making this application was to demonstrate that the designed mobile robot can move and capture the images needed for inspection, inside the aircraft's fuel tank.

The results of the practical application revealed that the use of mobile robots could be an important part of robot and human-assisted inspection techniques and tools. The use of high-performance software applications implemented on the robot can contribute to improving the quality, efficiency and effectiveness of fuel tank inspections, without the need for a long presence of maintenance personnel inside the tank.

The practical application consisting in the use of the hexapod mobile robot in maintenance activities was successfully realized. The mobile robot moved with some minor difficulties through the inside of the aircraft's fuel tank, but successfully completed its mission. He captured the necessary images, which I wanted during the inspection, a fact demonstrated by the transmitted images and the result of the application.

In conclusion, it is clear that the introduction of mobile robots in tank inspections in maintenance works is possible and human-robot interaction could lead to improved quality and safety of works and inspections in aircraft maintenance.

In the application, the robot was equipped with a secure video camera and was manipulated with a smartphone. Improving the solution, adding sensors and optimizing the software part of the robot, can be the subject of future research, to ensure the sustainability of research. The practical application was made for this project, just to check how another inspection can be performed inside the aircraft's fuel tank. Therefore, the practical application provides only a simplified example, of a complex robotic system, for conducting an inspection inside the aircraft's fuel tank.

2. IMPLEMENTATION OF THE PRACTICAL APPLICATION

The practical application was carried out in a hangar, on a Boeing 737-300 aircraft (fig. 1), and the aircraft was in type C control. This type of control is carried out only inside a hangar, and during this verification, most aircraft systems and subsystems are dismantled for detailed inspection and verification, then reassembled and tested for safety and continuing airworthiness certification. I must point out that not all type C controls also include the inspection of the inside of the aircraft's fuel tank. Regarding the Boeing 737-300 aircraft on which I performed the experiment I found that:

→ the tank has been inspected following a previous work;

→ controls and monitoring of the tank were performed, consisting in the exclusion of some old rivets and the installation of new ones.

This work was done to prevent fuel leakage.

Fig. 1 – Boeing 737-300 aircraft on which the practical application was made [13]

To make the practical application of the aircraft fuel tank inspection, we used a hexapod mobile robot and went through the following steps:

Step 1: Carefully study the documents and understand the inspection inside the aircraft's fuel tank. These are also called work tasks. Aircraft inspection requires that certain tasks be assigned to each segment of the aircraft. As an aircraft engineer, I was part of the control team in the wing and central fuel tank segments. Having the opportunity to inspect the fuel tank, I had the idea to use a hexapod mobile robot. The robot would be the solution to reduce the time that technical staff spends inside the tank, which, as mentioned above, is an extremely toxic environment.

Step 2: Access to the tank. In order to reach the central fuel tank of the airplane, where the inspection is to be performed, several pipes and the whole of the air conditioning part of the airplane cabin are dismantled, as can be seen in Figure 2.

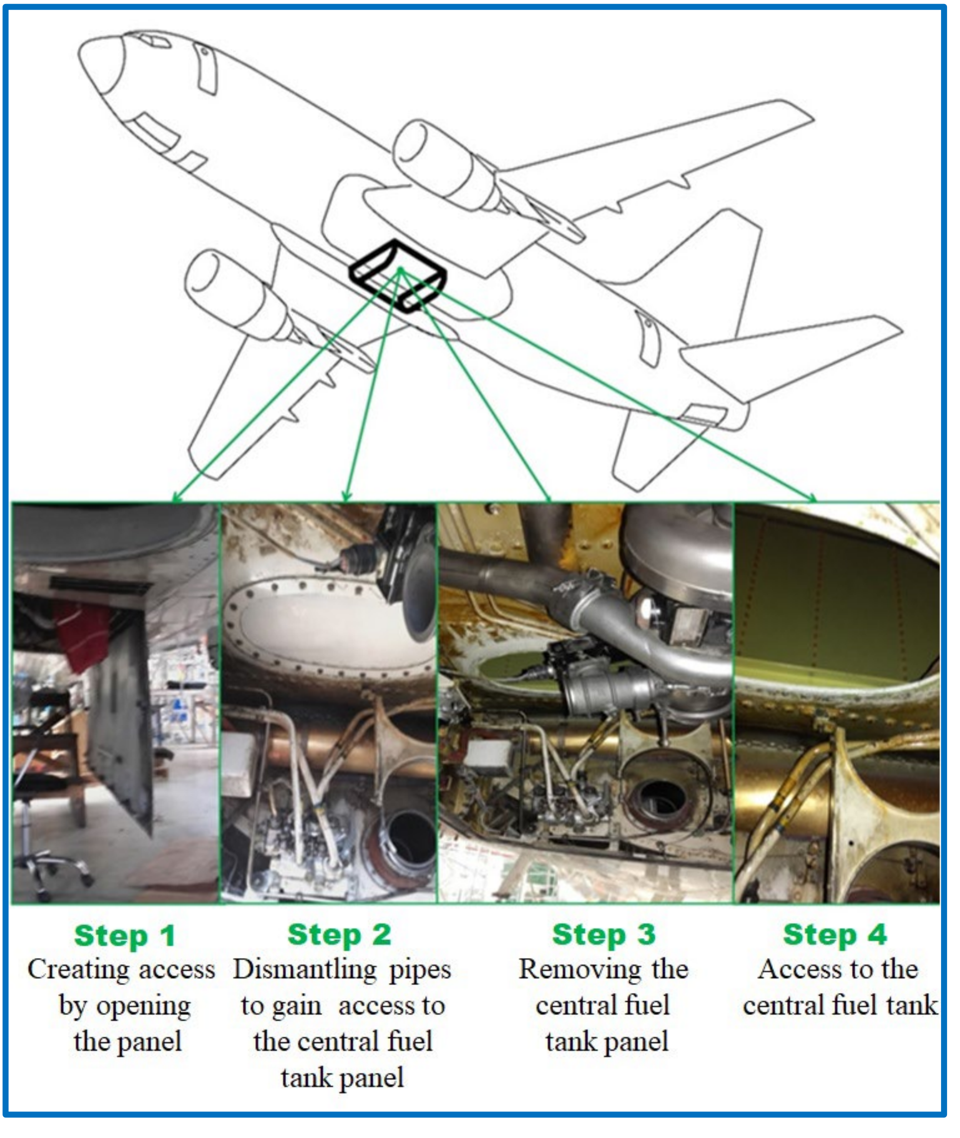

Fig. 2 – Access to the fuel tank of the Boeing 737-300 aircraft

In the following, I will describe the steps leading to the access to the central fuel tank, in order to carry out its inspection with the help of a hexapod mobile robot (fig. 2). Step 1 – the access to the tank is made by opening a panel, belonging to the air conditioning sector of the aircraft. This is quite simple, because the panel can be opened by means of clips. Step 2 is a more complex one, because it consists in dismantling some pipes and positioning them in a safe and secure place. Step 3 is a simpler step, because once the pipes have been removed, the tank panel has only screws that can be removed relatively easily. The last step, Step 4 – the access is made inside the aircraft's fuel tank.

Step 3: Venting the tank. After successful completion of each individual access step, the aircraft's fuel tank is to be vented. Its ventilation is very important, because the environment is very toxic and the kerosene vapors are very strong. Ventilation can take between 7 days and 2 weeks to reduce as much as possible the amount of kerosene vapor and other gases.

After the ventilation period ended, I started the actual practical application. As can be seen in the figure below (fig. 3), the access is quite difficult to achieve, because the entrance area to the tank is quite limited.

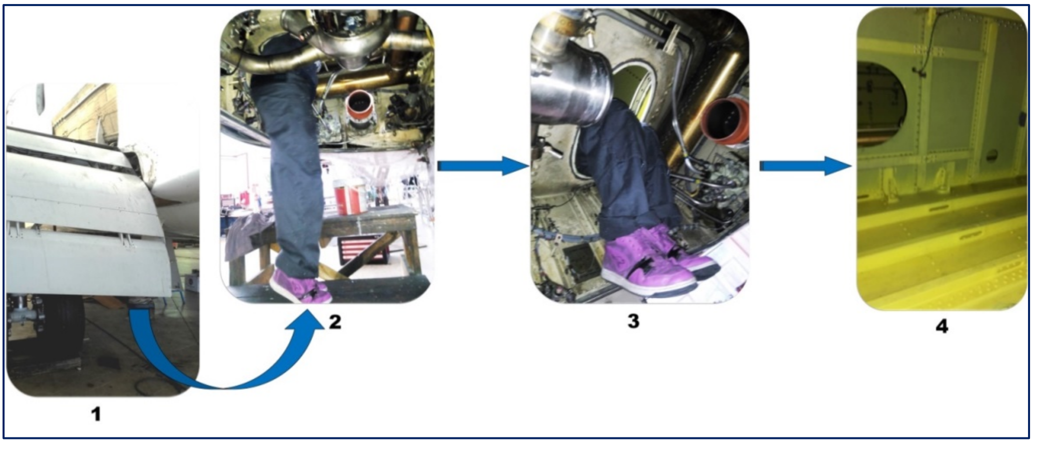

Fig. 3 – Entrance to the central fuel tank of the Boeing 737-300 aircraft

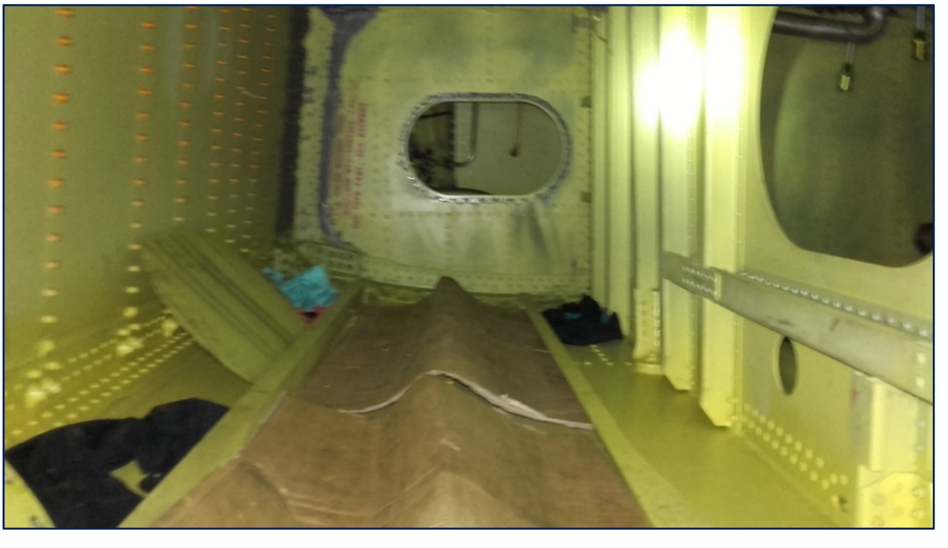

Fig. 4 – Removal of traces of kerosene left in the central fuel tank of the Boeing 737-300 aircraft

Step 4: The actual inspection performed by the robot. The shape of the tank is massive, consisting of frames of up to 7 mm, as can be seen in Figure 5.

That was why I used a hexapod robot with elongated legs. Thus, the robot can go over the frames, only with a slight difficulty, depending very much on the operator's coordination.

But once inside the tank, the robot was able to perform the inspection, as shown in the figures below.

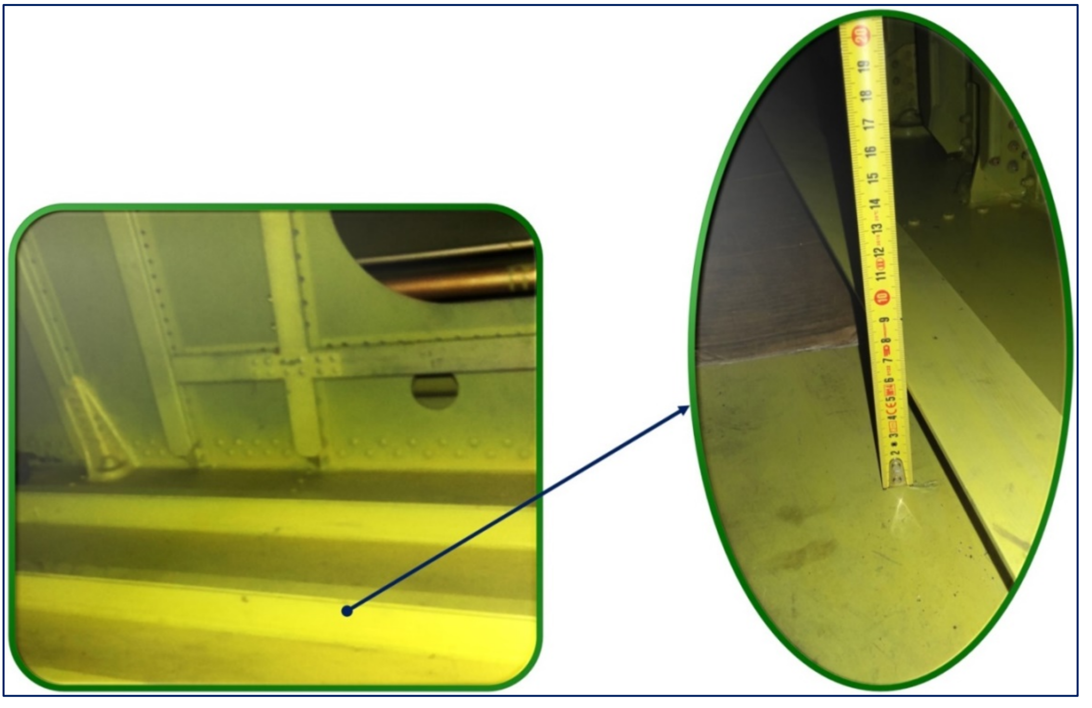

Fig. 5 – Identification and measurement of frames in the central fuel tank of the Boeing 737-300 aircraft

It is very important to mention that, by identifying the frames and measuring them (see fig. 5) we were able to establish the limits of the hexapod mobile robot.

The measured frames are 7 mm and as a result, we designed the length of the robot's legs, in order to overcome the obstacles in the tank, as can be seen in Fig. 6.

The hexapod mobile robot was guided by a smartphone, but I must point out that the operation and guidance of the operator is the main basis in overcoming all obstacles, so that the hexapod mobile robot can complete the task of inspecting the tank aircraft fuel plant.

I made the practical application in two ways. In the first method, the operation and guidance of the hexapod mobile robot was performed inside the central fuel tank of the aircraft, and in the second method, from outside it. By the first method, I set out to observe the movement of the robot inside the tank.

We watched very carefully if the robot could overtake the frames and if it could move, even when there were still traces of kerosene in the tank.

The experiment was successfully completed, and the hexapod mobile robot overcame all obstacles, as can be seen in the figure below.

Fig. 6 – The hexapod mobile robot inside the central fuel tank of the Boeing 737-300 aircraft

The **second method** was to guide the hexapod mobile robot from outside the tank, which was a challenge. The question has been whether the travel commands will reach the robot in real time. It was only equipped with a Sony camcorder, and the commands were transmitted from a smartphone.The images transmitted by the Sony video camera were practically the ones I saw on the phone and in this way, I gave commands, through which the robot began to move slowly. I must point out that I performed the experiment very close to the plane, at a relatively short distance from the robot, more precisely, close to the entrance to the central fuel tank of the plane.

At the beginning, with great caution, I managed to give the robot a command for slow movement. The average speed of the robot was 3 m / min. The Sony camcorder gave me a real advantage, because the image quality was impeccable and this can be seen in the images presented. Every moment of the experiment was captured by the video camera, but I focused on the inspection of the tank. A very important thing must be emphasized, namely the fact that we achieved efficient communication between the phone we used and the hexapod mobile robot.

When I moved about 3 meters away from the plane, I found that the signal remained just as good and in this way, I assumed that the guidance / control of the robot can be done from a greater distance.

The inspection of the central fuel tank of the aircraft with the help of the hexapod mobile robot was carried out and completed successfully, because: the robot-human communication was very good; the robot moved in the tank with a speed of 3 m / min, being able to capture the frames that I wanted to highlight in particular and that followed the installation of rivets. The time in which the inspection of an area of 5 meters took place was 15 minutes in which 10 images were taken.

The images transmitted by the robot showed that the tank complies with the AMM (Aircraft Maintenance Manual) [12] norms, the rivets are mounted properly and we did not notice any malfunction leading to a possible fuel leak on the aircraft fuselage.

Following the experiment, we came to the conclusion that the hexapod mobile robot managed to meet all the requirements imposed by the inspection procedures. The inspection took place over a period of 2 hours, and the average speed of the robot was 3 m / min, given that the geometry of the robot's configuration allows the correct movement inside the tank.

Following the practical application, we demonstrated that the maintenance can be improved by integrating a robot, which would bring great benefits to the human operator, because the aircraft's fuel tank is an extremely harmful environment, which can affect human physical and mental health, while the robot can successfully intervene and help.

3. CONCLUSIONS

Entry into the aircraft fuel tank is required for inspections and modifications, but these works may present a risk factor for technical personnel. The maintenance of the aircraft fuel tank can be done safely if the technical staff is trained and has the necessary equipment for the work. In this area of aircraft safety and maintenance the mobile robots can successfully intervene.

Robotics automation provides the flexibility needed to achieve shorter production cycles, new ways of packaging as a form and design, and the creation of new product variants and batch manufacturing. Compared with traditional dedicated automations, robot lines are shorter and allow for much better space utilization. Robot automation is an excellent alternative to manual operation.

In addition to reduce the working time and enhance safety of maintenance staff, mobile robots can play an important role. The decrease in the number of accidents and the increasing demand for labor protection legislation are good reasons for moving to robots. Entry into airplane fuel tank is needed for inspections and modifications. And this work may pose a risk factor for the technical staff.

Therefore, this paper aims to implement a mobile hexapod robot. Due to its characteristics, the robot can easily sneak into the fuel tank of the aircraft and the operator can guide it from the outside to facilitate his aircraft maintenance activities.

REFERENCES

[1] A. Ghasempoor and N. Sepehri, A measure of machine stability for moving base manipulators, in *Proceedings of the IEEE International Conference on Robotics and Automation*, vol. **3**, pp. 2249-2254, 1995.

[2] S. Hirose, H. Tsukagoshi and K. Yoneda, *Normalized energy stability margin: Generalized stability criterion for walking vehicles*, in Proceedings of International Conference on Climbing and Walking Robots, pp. 71-76, 1998.

[3] E. Garcia and P. A. G. de Santos, A new dynamic energy stability margin for walking machines, in *Proceedings of International Conference on Advanced Robotics*, pp. 1014-1019, 2003.

[4] J. K. Davidson and G. Schweitzer, A mechanics-based computer algorithm for displaying the margin of static stability in four-legged vehicles, *Transaction of the ASME Journal of Mechanical Design*, vol. **112**, no. 3, pp. 480-487, 1990.

[5] B.-S. Lin and S.-M. Song, Dynamic modeling, stability and energy e_ciency of a quadrupedal walking machine, in *Proceedings of the IEEE International Conference on Robotics and Automation*, vol. **3**, pp. 367-373, 1993.

[6] S. Sugano, Q. Huang and I. Kato, Stability criteria in controlling mobile robotic systems, in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, vol. **2**, pp. 832-838, 1993.

[7] D.-O. Kang, Y.-J. Lee, S.-H. Lee, Y. S. Hong and Z. Bien, A study on an adaptive gait for a quadruped walking robot under external forces, in *Proceedings of the IEEE International Conference on Robotics and Automation*, vol. **4**, pp. 2777-2782, 1997.

[8] J. Kim, W. K. Chung, Y. Youm and B. Lee, Real-time zmp compensation method using null motion for mobile manipulators, in *Proceedings of the IEEE International Conference on Robotics and Automation*, vol. **2**, pp. 1967-1972, 2002.

[9] J.-H. Lee, J.-B. Park and B.-H. Lee, Turnover prevention of a mobile robot on uneven terrain using the concept of stability space, *Robotica*, vol. **27**, no. 05, pp. 641-652, 2009.
[10] K. Yoneda and S. Hirose, Tumble stability criterion of integrated locomotion and manipulation, in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, vol. **2**, pp. 870-876, 1996.
[11] * * * www.image-sensing-solutions.eu
[12] * * * AMM (*Aircraft Maintenance Manual*).
[13] * * * http://www.boeing.com