INNOVATIVE AIRPLANE GROUND HANDLING SYSTEM FOR GREEN OPERATIONS

M. Battipede*, A. Della Corte*, M. Vazzola*, D. Tancredi**
***Politecnico di Torino, Italy **West Virginia University, USA**

Keywords: *airport, ground, operations, renewable, energy*

Abstract

The aim of this work is to develop a new concept of taxiing, in order to reduce the pollution in terms of noise and gas emission and to introduce a higher level of safety during ground operations.

In the area close to the airport gates, the airplane ground handlings are currently performed through the airplane engines, which have the task of providing the trust necessary to move the airplane to the runway.

Pollutant emissions and noise level near the gates, however, could be drastically reduced by introducing an innovative autonomous tractor called CHAT (Clean Hydrogen Autonomous Tractor), developed from the standard towbarless pushback tractor.

The ground operations could be basically modified by extending the time in which the airplane engines are idle and the airplane is towed by the tractors powered by renewable energy.

1 Introduction

CHAT is basically an autonomous Unmanned Ground Vehicle (UGV) that is under the Traffic Management and Control (TMC) authority. The procedure is very easy and can be resumed as follows: CHAT is refueled with hydrogen before starting its mission. It communicates continuously with the TMC unit in order to receive details about the current mission, updates about the airport situation and, eventually, a new assignment.

CHAT autonomously connect to the front landing gear, using towbarless technology, and start to tow the airplane towards the runway. Once CHAT reaches the runway, it releases the airplane, which is ready to start its engines using the Auxiliary Power Unit (APU).

After this phase, CHAT reaches the landed airplane and tow it to the assigned gate. During normal operations, CHAT always moves in taxi ways and avoids using the runways, which are exclusive use of the air traffic. These operations can be repeated in a continuous process of pushing and pulling for approximately 20 hours.

The impact of the CHAT employment can be advantageous for the vector companies, as well as for the environment, not to mention the reduction of noise, pilot workload and potential risks caused by jet blasts.

The employment of CHAT could effectively make the taxing process cheaper, faster and safer.

This system has a great potential on decreasing the airplanes' emissions during ground maneuvers. This can be understood by taking into account the amount of kerosene burned by airplanes during taxiing operations. Considering a specific fuel consumption of *17.1 g/kN*s* [1], and considering a normal taxi trust requirement of *100kN* for an A320, it can be assumed a total engine fuel consumption of *1.7kg/s*. For a taxi phase of about 10 minutes, an A320 airplane needs approximately *1 ton* of kerosene. This calculation can vary with the taxi distance and with the type of engine used, but it is very easy to reach *500kg* of kerosene even with small engine or short taxi runs.

This quantity must be multiplied by the global annual movements, which is a number rapidly increasing between *60* and *70* millions [2]. It can be said, thus, that the employment of a CHAT fleet could lead to a kerosene saving of *30* to *35* millions of tons per year.

Considering an average world airplane movement of *60* millions of aircrafts, it is easy to calculate the amount of carbon dioxide produced every year by airplane taxiing. The calculation can be done considering that, in the combustion process, one kilogram of kerosene produces *3.2 kg* of carbon dioxide. The kerosene amount burned every year by the word civil aviation can be approximatively estimated around *30* millions of tons, which must be multiplied by *3.2* to obtain almost *96* millions of tons of carbon dioxide, which is the yearly taxiing cost in terms of emissions. Those emissions, moreover, are often produced near highly populated areas, as it is always the case of major traffic airports. The possibility of avoiding these emissions will not only have great and direct benefits on the quality of air within the airport areas, but it will also be beneficial on a global scale. The total saving of kerosene, estimated to be between *30* and *35* millions of tons of fuel every year, has been calculated considering the CHAT system fully operational in all the major airports.

Besides the eco-efficiency benefits, major safety improvements will be another fundamental aspect of the CHAT exploitation. Fatalities like the infamous 27th March 1977 in Tenerife, Canary Islands (E), or the one of the 8th October 2001, Linate Airport Milan (I), would probably have been avoided by the use of an automatic towing systems, which does not rely directly on human vision.

The employment of CHAT could have interesting impacts also on:

- the hydrogen costs: increasing the hydrogen production and the number of hydrogen refueling stations, in fact, could lead to a general reduction of the hydrogen costs;
- flight fares: the increasing efficiency during the taxi phase could lead to a general reduction of ground handling costs, which could help the vectors to save money and reduce the flight fares, with a consequent beneficial impulse of the commercial flight market.

.

2 Power Calculation

2.1 PV Systems

The power necessary to move the CHAT system has to be calculated to verify if an airport can operate autonomously, by producing the requires amount of hydrogen directly on site.

One possibility is to transform the local waste produced by nearest cities in H_2. There is an interesting study by the London hydrogen Partnership [3] that shows how a city like London, with an average yearly production of *1.3* millions of tons of waste, could potentially have a daily hydrogen production of *111* tons, from the gasification process or alternatively of *30* tons from the anaerobic digestion. This production could be enough to supply all the London airports with the necessary amount of hydrogen. It has been estimated, in fact, that the required hydrogen supply for standard operations of the London Heathrow Airport, for example, is about *4* tons of hydrogen per day.

Another solution consists in photovoltaic energy used to transform water into hydrogen. Even if this is probably the most expensive solution in terms of initial investment for the airport, it is also the one that requires less research to be actuated before the industrial production of hydrogen can take place. The solar power, however, in notoriously low efficient and implies the availability of large surfaces for the installation of photovoltaic panels. To make a preliminary assessment of the actual capabilities of hydrogen production, ortho-photos of existing airports have been analyzed. The potentially available surfaces which could be used to host photovoltaic panels are the areas between the taxi lanes and the runways, plus the flat roofs of terminals and airport buildings. For the sake of generality, airports of different dimensions, locations, climates and infrastructure conditions have been considered. Location plays also a very important role, as the solar radiation can vary considerably depending on the airport latitude.

The analysis has revealed that, for 90% of considered airports, the surface availability can be considered enough to produce the whole amount of energy required to run the airplane ground handling system effectively.

To case of the Milan MPX airport is hereinafter reported. Milan Malpensa (MPX) is an international airport located at a medium latitude with an average annual solar irradiation of *1100 kWh/m*^{2}. A standard solar panel with an efficiency of *10%* can obtain an annual production of *110 kWh/year*.

With this potentials, an hydrogen production of almost *3kg* per square meter per year can be achieved, assuming to have a hydrolyzer with an average efficiency of *60%* [4]. Ortho-photos reveal that Milan MPX has a surface of *2.5km*^{2} of PV modules: considering the weather and the solar power associated to the latitude, there could be a production of *13 ton* of hydrogen per day.

Fig - Available surface for PV system in Malpensa Airport (green areas)

Since the Milan MPX hydrogen consumption is estimated in *3 ton* of hydrogen per day, it can be deduced that this airport could be able to produce by itself 100% of the energy required by the whole fleet of CHAT tractors.

For the majority of the airports, moreover, the surface availability is so extended, if compared to the airport hydrogen theoretical consumption, that it could be potentially used for extra production of energy or hydrogen, to be sold to third parties as a mean to absorb more rapidly the costs arising from the plant installation. In big airports, where the available surface may not be enough to saturate the request of power supply from the water hydrolyzation, extra electricity could simply be provided by the standard electricity distribution network.

The local production has to be established according to the surface availability and the investments involved. The installation of a solar power plant, in fact, is also an economical effort and not only a technological challenge. The cost of a solar panel can be estimated around *2.5-11.2€/Wp* [5], where the *Wp* is the peak power that the panel can generate in a standard situation. Starting from the average value of *6.7€/Wp* it can be calculated that the cost for the modules needed to produce the hydrogen in Milan MPX is *14M€*. This cost, however, is easily amortized: CHATs, in fact, allows a fuel saving of almost *500kg* for each take-off or landing. Considering the standard activity of the Malpensa MPX airport, it can be estimated that the overall saving of Kerosene could reach *25M€* per year.

2.2 Hydrogen system

To guarantee the necessary storage capabilities to operate the CHAT system continuously, it is necessary to evaluate accurately the airport daily hydrogen supply, that can come from internal hydrolyser-assisted production or from external suppliers, and the daily requirements which must be incremented by an extra amount of stock for emergency situations. For an airport of medium dimensions, the daily production of hydrogen can be estimated around the *3* tons per day, whereas the CHATs requirement is half this value. Therefore, a storage capacity of about *2* tons has to be guaranteed in order to maintain the whole system.

If the storage pressure is *1 atm,* the 2 tons of hydrogen would correspond to a volume of stocked hydrogen of *22000-23000Nm*^{3}, which is more or less the same volume of the facility used to store the kerosene at a big airport such as the Paris Charles de Gaulle. One of the most interesting example is represented by the Munich airport hydrogen facility [6], which supplies the shuttles, terminal buses and service trailers within the airport as well as private transportation outside the airport. Technologies and procedures are already in use and certified.

The concept adopted by the Munich airport is based on a central cryogenic storage system which is used to store the hydrogen that can be produced by a steam reformer or a hydrolyzator or can be purchased from external suppliers. The cryogenic tanks can stock very high quantities of hydrogen with a reduced risk of explosion. They are usually associated to a vaporizer and to a secondary stock system, where the hydrogen is in gaseous form, for short term demand. The system can feed the airport facilities as well as public customers. In the first case the refueling procedure is carried out manually, whereas in the second case the procedure is assisted by a robot, to reduce the risk of incidents.

The same automatic system could be easily used to provide an automatic hydrogen refueling system for CHATs. The storage facility could be positioned either inside or outside the airport area. In both cases, the hydrogen could be safely transported and fuelled inside the airport boundaries [7]. The *350bar* metal-hydride tanks could be dimensioned to contain the amount of hydrogen necessary to operate the CHATs, whereas the cryogenic tanks could be dimensioned to store the exceeding daily summer production, to compensate for the less favorable solar and weather conditions typical of the winter season.

CHATs refueling could be performed autonomously without retarding or encumbering the manual refueling of other vehicles. Refueling could be scheduled during less intense traffic hours on the non operating CHATs, which can reach the refueling facility without affecting the normal aircraft operations.

Similar facilities of the same dimensions already exist and operate effectively: they can be found in hydrogen productions industries or hydrogen refueling station [8] even if they are dedicated to different missions.

3 CHAT feasibility

The initial idea for the CHATs (Fig. 1) is to create an hydrogen powered machine to make the taxiing process fully autonomous and unmanned.

To reduce the impact in terms of design, production, maintenance, spare parts and thus costs, a single CHAT model has been designed. The size has been selected with the versatility requirement: CHAT, in fact, must be compact enough to pass under the nose of small airplanes (such as ATR42) and to handle, at the same time, all the possible landing gear sizes (up to A380), with the same towbarless system.

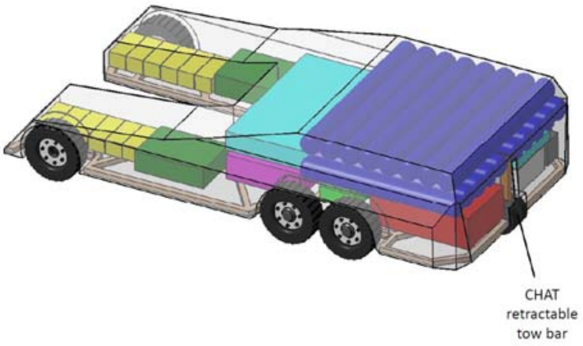

Fig. 1. CHAT concept

According to a recent market analysis, the towbarless tractor technology is widely in use in many international or minor airports and their lifting capabilities have already been dimensioned to accommodate very large aircrafts, such as the A380.

The CHAT system has been initially dimensioned in terms of power requirements, to perform a push back of a small-size regional airplane in a normal-size airport at *5km/h* and a taxi phase at *20-50 km/h,* in accordance with the airport procedures. The system effectiveness has been investigated by analyzing the performance on a very large mainline airplane, such as the A380, with a push back of *5km/h* and a taxi phase of *30km/h*. A CHAT with a power supply of *300kW* has been considered enough to perform the push back operations on any airplane. However, this power is not adequate to allow the widebody airplanes to reach the average taxi speed. For this reason a special train system has been designed to connect together two or more CHATs. The operational concept could be the following: once the first CHAT has pushed the airplane back to the taxi line, the second CHAT can approach and occupy the free space left available by the first one (Fig. 2). It has been estimated that a train of two CHATs can be perfectly able to pull large-dimension airplanes at the required speed to the beginning of the runway.

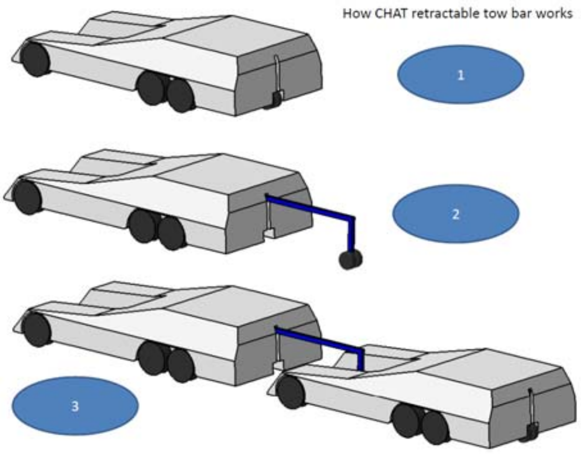

Fig. 2. CHATs connection system

Avoiding the use of tow bars between two CHATs and between CHAT and airplane, a fully automated connecting procedure can be employed.

A layout analysis has been performed with the intent of verifying the possibility of installing a *300kW* power system on a compact size tractor, on the basis of the existing commercial fuel cell systems. The ones used for this analysis are actually manufactured and installed on large buses, employed for public transportation. The layout analysis of Figures 3 and 4 is hence only an initial feasibility study and it is clear that the volume organization can be optimized.

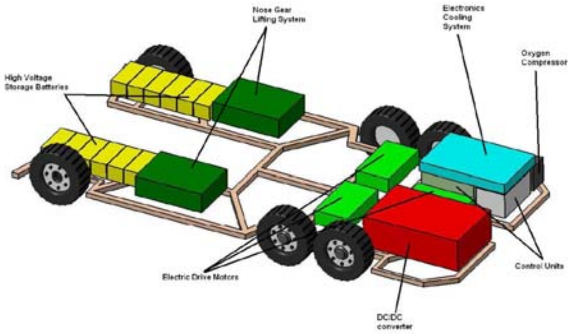

Fig. 3. Layout analysis: first layer

The system is made up by three electric engines (light green boxes in Fig.3), one large fuel cell (purple box of Fig. 4), a storage battery system (yellow boxes), the control units (light and dark gray boxes in Fig.3) and a towbarless lifting cradle (dark green boxes). The analysis reveals that, once all the components have been accommodated, there is still enough room in the CHAT to store up to ten cubic meters of hydrogen (blue cylinders of Fig. 4). Using normal hydrogen tanks at *350atm,* the storage capabilities can reach up to *1500*Nm^3 of hydrogen, which gives the CHAT enough power to operate up to *20* hours continuously.

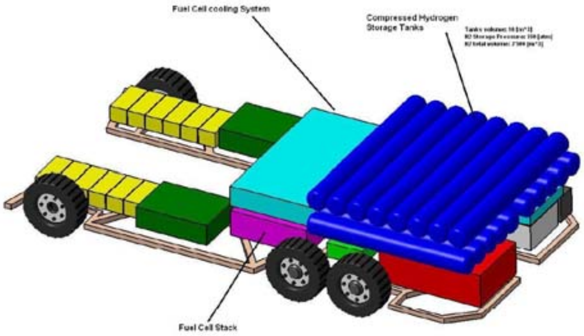

Fig. 4. Layout analysis: second layer

4 Airport System Integration

4.1 CHAT procedures and CHAT-aircraft interaction

In the CHAT system implementation, the control for the UGV will be of crucial importance for both safety and efficiency reasons.

As shown in the feasibility study, CHAT can be basically developed employing state-of the art components or, as for the fuel cells, technologies which are in their pre-competitive phase. The real challenging and innovative part of the project, thus, consists in the development of reliable procedures and algorithms, capable of controlling consistently and efficiently the CHATs in safety-critical operations, relieving the human operators from workload and responsibilities. It must be noticed, however, that modern industries have been basing their logistics on automated Guided Vehicles (AGV) for years, for the movement of goods. Applications vary for capabilities and complexity, from few lightweight vehicles for small factories, to over 70 towing vehicles which move systematically naval containers in the Port of Rotterdam [9]. In the military field, UGVs with human-like autonomous capabilities are expected to be employed between 2020 and 2030 [10], whereas autonomous driving capabilities are supposed to be acquired and standardised within the next few years. This hypothetic timeline is actually consistent with the time required for the design, construction and qualification of the related infrastructures.

Safe and efficient automated processes involve the implementation of effective navigation techniques, both for indoor and outdoor operations. These techniques range from the very low-cost and easy implemented systems, based on predefined paths, traced by tapes or wired connections, to complex and expensive architectures, which have the advantage of being flexible and capable and safe and fault tolerant operations. They employ expensive devices, such as laser and gyroscopic navigation sensors.

The main feature of CHAT procedures and CHAT-aircraft interaction are summarized in Table 1.

	Traffic Management and Control Operator	CHAT Tractors
Location	Control Tower	Taxi lanes, parking areas
Requirements	Knowledge of position, path and estimated time of arrival for every CHAT	Real time communication of status, position and path
Actions	Full authority over CHATS: possibility of interrupting and modifying CHAT operations.	Receive orders from the Control Tower and from human operators. Possess obstacle avoidance capabilities.
Needings	New interface for control and CHAT management	Reliable datalink with Tower. Sensors for path following and obstacle avoidance.

Table 1. Requirement and characteristic of Control Architecture

The control unit is located in the Control Tower, where Traffic Management and Control is performed. To guarantee successful and safe operations, the control unit must be constantly provided with updated information from every single CHAT on the field. The transmitted information will report data such as position, speed, assigned path, battery charge and detected malfunctions. The central core of the Control Unit has full authority for path generation, docking and minor operations. The key requirement for the global system, hence, is the necessity of a fast, reliable and secure data-link between the Tower and the CHATs.

The CHATs, however, will retain, in any case and at any moment, the authority to perform obstacle avoidance manoeuvres in emergency situations. As far as emergency manoeuvres are concerns, moreover, the procedures must account for the possibility of a manual override of the automatic control system: in case of failures or any other emergency, in fact, ground personnel must have the possibility to manually remove the CHATs from the operative area and then, if necessary, restore the automatic control. To allow manual operations, CHAT must be provided with a crew station equipped with a small cockpit. This configuration is also useful for storage or rapid and unplanned CHAT movements, or any other “out-of-service” exercise.

Studies and applications of autonomous docking between vehicles of different configuration have already been conducted by NASA, in a program for space exploration using robots [11]. These studies have highlighted the necessity of performing the docking procedure between the CHAT and the aircraft in pre-defined areas, purposely instrumented to improve precision and reduce the operation time. The docking platform will be equipped with underground weight sensors and precise distance measurements, to provide the required information on the relative and absolute airplane and CHAT position, throughout the whole docking procedure.

4.1 User Interface

Another requirement arises from the interaction of the CHATs system with human operators, who will eventually supervise the operations from the Control Tower and resolve potential conflicts and errors caused by the Traffic Control Algorithm.

The operator needs an efficient, clear and effective interface which has to show all the required information for quick and unequivocal decision making. A preliminary sketch of a possible GUI is presented in Figure 4.

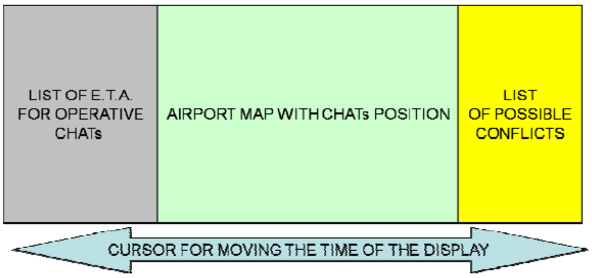

Fig. 4. Possible layout of the GUI

The graphical interface consists of a central section showing a simplified airport map, reporting the CHATs position. A lateral section is dedicated to the list of the CHATs Estimated Arrival Time whereas another section contains warnings and messages reporting possible conflicts (e.g. CHATs that pass close to other CHATs).

The interface is also provided with a sliding cursor which can be moved forward, in order to produce a prediction of future evolution of the system, based on actual decision and status. This type of GUI integrates point-and-click features: by clicking on a CHAT in the map, a pop-up window will appear reporting all the CHAT information and giving the operators the chance to interrupt or modify the planned operations. Advanced command recognition capabilities (e.g. voice recognition) could also be integrated to effectively reduce the human operator workload. The effectiveness of advance tactical graphic interfaces has already been studied for a decision support system named ERATO [12], introduced and tested in the main air traffic controllers cognitive processes. In an international airport with intense traffic, this sort of analysis will represent a strict prerequisite for a successful implementation of the CHAT system.

References

[1] Svoboda C, Turbofan engine database as a preliminary design tool, *Aircraft Design.* Vol. 3, No. 1, March, pp. 17-31, 2000.

[2] International Civil Aviation Organization, *ACI Annual World Airport Traffic Reports (WATR).* www.aci.aero, 2008

[3] Joffe D, *The Potential for hydrogen Production from Waste in London*, London hydrogen Partnership, 2006

[4] Cavallaro C, Chimento F, Musumeci S, Sapuppo C and Santonocito C, Electrolyser in H2 Self-Producing Systems Connected to DC Link with Dedicated Phase Shift Converter, *Proceedings of the International Conference on Clean Electrical Power ICCEP*, Capri (NA), Vol. 1, pp 632 – 638, 2007

[5] Carmichael D, Noel T, Development of Low-Cost Modular Designs for Photovoltaic Array Fields, *Transactions on Power Apparatus and Systems*, Vol. 1, No. 1, pp 1005 – 1011, 2001

[6] Dettweiler G, *Hydrogen project at the Munich Airport*, Proceedings of the HYFORUM, Munich, 2000

[7] ISO/PAS 15594 *Airport hydrogen fueling facility* - 2004

[8] Pehr K, Sauermann P, Traeger O, Bracha M, Liquid hydrogen for motor vehicles — the world's first public LH_2 filling station, *International Journal of Hydrogen Energy,* Vol. 26, No. 7, pp. 777-782, 2001

[9] Warmerdam J, Knepfle M, Bidarra R, Bekebrede G, and Mayer I, Simport: a multiplayer management game framework, *In Proceedings of the 9th International Conference on Computer Games*, Dublin, Ireland 2006.

[10] Committee on Army Unmanned Ground Vehicle Technology, *Technology Development for Army Unmanned Ground Vehicles,* National Research Council of the National Academies, Vol. 1, 2002

[11] Wilcox BH, ATHLETE: An Option for Mobile Lunar Landers, *Proceedings of the IEEE Aerospace Conference,* Big Sky (MT), Vol. 1, pp. 1-8, 2008

[12] Bressolle MC, Benhacene R, Boudes N Parise R, Advanced decision aids for Air Traffic Controllers: Understanding different working methods from a cognitive point of view, *Proceedings of the 3rd USA/EUROPE ATM R&D Seminar,* Naples (I), Vol. 1, pp. 1-10, 2000

Copyright Statement