# Geometric Feasibility of a Flexible Cask Transportation System for ITER[1]

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## 1. INTRODUCTION

One of the remote operations that has to be carried out in the International Thermonuclear Experimental Reactor (ITER) is the transportation of sealed casks between the various ports of the Tokamak Building (TB) and the Hot Cell Building (HCB). The casks may contain different in-vessel components (e.g, blanket modules, divertors) and are designed for a maximum load of about 80ton.

To improve the safety and flexibility of ITER Remote Handling (RH) transport vehicles, the cask is not motorized by itself, but instead, a motorized platform carrying the cask was proposed in [1]. Under this concept, should a problem arise, it is possible in most cases to remove the platform from underneath the cask, which is capable of self-support. When the geometry of the vehicle and the walls relative positions prevents platform removal, a rescue vehicle is required to carry out the rescue procedures. Along the route between the Tokamak Building and the Hot Cell Building, the flexible cask transporters must overcome some critical locations, for which the feasibility of rescue manoeuvres must be carefully analysed.


Figure 1: a) Schematic representation of a rhombic vehicle, showing its main dimensions; b) Vehicle alignment errors and clearance space ($space = \min\{\overline{AA'}, \overline{BB'}\}$) in the TB gallery.

This paper addresses the geometric feasibility of the flexible cask transportation system proposed in [1, 3, 5], taking into account the proposed vehicle kinematics. The feasibility issues studied include planning smooth paths (based on cubic spirals [2]) to increase safety, the discussion of building constraints by the evaluation of the vehicle spanned areas when following a planned path, and the analysis of the clearance required to remove the platform from underneath the cask at different possible failure locations. Simulation results are presented for the recommended trajectory, the spanned area and the rescue manoeuvres at critical locations along the path.

## 2. MAIN OBJECTIVES AND ASSUMPTIONS

The vehicle has a rhombic configuration, with two steering-and-driving wheels placed along the vehicle longitudinal axis. This configuration allows any type of motion, e.g., forward, backward, sideways. The current reference design consists of an air cushion inductive AGV, whose guidance and navigation systems are based on a metal stripe and on-board emission/reception antennas whose generated field is modified by the passive stripe.

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It is assumed that the platform is rigid. Nevertheless, a 2-body segmentation of the platform is envisaged as an improved solution to recover from air compressor failures by removing the shorter modules one at a time. As such, two different lengths, corresponding to full and half-body length, will be considered for rescue manoeuvres. The vehicle dimensions, shown in Figure 1a), are those presented in [5], i.e., platform length $l = 8500$ mm, platform width $w = 4000$ mm, distance between drive units $l' = 6300$ mm.

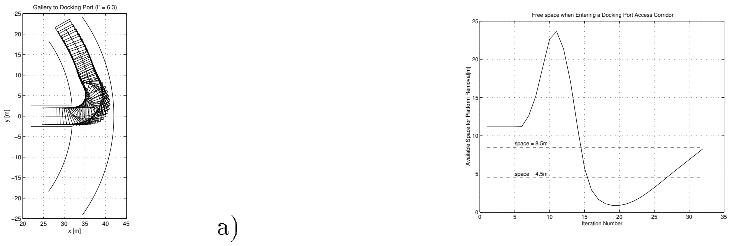
All building dimensions were obtained or extrapolated from the most recently available ITER drawings (end of 1997). The maximum and minimum considered radii of the TB gallery boundary circles are $r_{max} = 42$ m and $r_{min} = 32$ m, respectively (see Figure 1). The width of a typical VV docking port entrance is 5000 mm. The laydown hall entrance is 4900 mm wide. The laydown hall width is 10250 mm, and its length is 20100 mm. Inside the HCB, only the last docking port is considered, since it corresponds to the most difficult situation, from a geometric standpoint. Its entrance is 5500 mm wide.

## 3. CRITICAL LOCATIONS ALONG THE PATH

This subsection tackles the spanned area and rescue clearance issues for the most critical locations composing the path between the TB and the HCB. A more thorough study of all the locations along the path can be found in [4]. The analysis of each location corresponds to a subsection. Some results are based on closed form expressions derived in [4], others were iteratively computed in Matlab. In both cases, simulations are parameterized by the vehicle and building dimensions, hence it is possible to cope with future modifications. The studies made concentrated on determining smooth paths to be followed by both steering wheels, so that “ad-hoc” and/or operator-driven manoeuvres could be avoided.

### 3.1 Between the TB Gallery and the VV Docking Ports

The path between the TB gallery and the VV docking ports is characterized by switching from a 37 m radius circular path to a radial path (or backwards). This manoeuvre is hard to accomplish due to the narrow entrance to the docking ports and the relatively narrow space in the TB gallery. However, simulations show (see Figure 2a)) that it is possible to find a cubic spiral path to overcome the switching smoothly and without colliding with the gallery and docking ports walls.

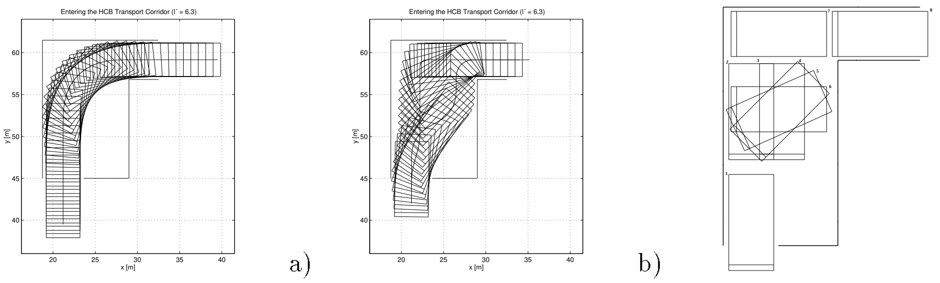



a) b)

Figure 2: Vehicle moving from the TB gallery to a VV docking port: a) recommended smooth path and corresponding spanned area; b) available clearance space for rescue, along the path in a).

Results concerning the rescue clearance ($\overline{AA'}$ in Figure 1b)) along this path are illustrated in Figure 2b). The iteration number in the x-axis label refers to the simulation steps depicted in Figure 2a) as successive vehicle locations. From the plot, it can be seen that there are locations along the path (roughly iterations 14 to 32) where, should the vehicle stop due to some malfunction, it would not be possible to remove the platform from underneath the cask, because the clearance is below 8.5 m, the total length of the platform. With a 2-body platform, and considering a 4.5 m long body to include the additional rear space for the control system, the range of locations for which this type of rescue would not be possible is reduced (roughly iterations 15 to 27), as theoretically each body could be removed at a time. Notice that platform removal is possible for all the other locations.

Results concerning rescue in the gallery refer to the worst case anticipated scenarios (justified in [4]) for vehicle misalignment, i.e., both wheels deviated +100 mm from the track corresponds to the worst deviation error $d$ (= 100 mm), while one of the wheels deviated +100 mm from the track, and the other wheel deviated -100 mm from the track corresponds to the worst orientation error $\beta$ ($\simeq 2°$). The definitions of $d$ and $\beta$ are depicted in Figure 1b). The smallest clearance $\overline{AA'}$ corresponds to the worst case deviation $d = 100$ mm and orientation $\beta = 2°$ and was determined to be 9.59 m. Therefore, space is enough for platform removal/insertion when the vehicle is moving in the gallery, even for the worst case scenario.



a) b) c)

Figure 3: Vehicle moving from the laydown hall to the HC transport corridor: a) recommended smooth path and corresponding spanned area with one path for both wheels; b) recommended smooth path and corresponding spanned area with separated paths for each wheel; c) manoeuvre-based solution.

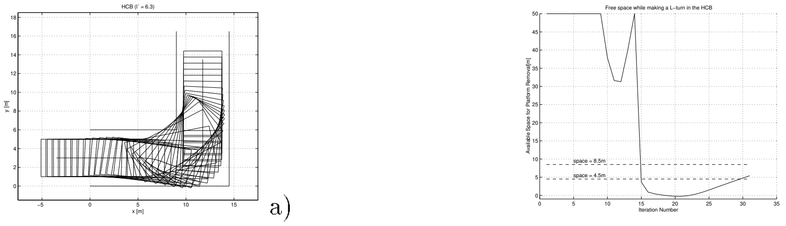
### 3.2 Between the Laydown Hall and the HC Transport Corridor

This location allows several alternatives concerning the path topology. The single path solution, where both the front and rear vehicles follow the same path (similar to the one presented in the previous section) is shown in Figure 3a). Under this scenario, collision with the left wall is unavoidable, for the current building configuration. When separate paths for each wheel are used (see Figure 3b)) there is no collision, but it can be shown that the available rescue clearance space is reduced when compared to the range of situations for which the platform is removable under the single path solution. Furthermore, there is no criterion to quantify the smoothness of the vehicle motion in this case. Finally, a manoeuvre-based strategy is depicted in Figure 3c). Under this solution, the vehicle goes through a sequence (1–8) of poses from the Laydown Hall entrance until the HC transport corridor entrance. This strategy, besides involving several manoeuvres which require operator intervention, may cause serious rescue problems in case of an air cushion failure, since the platform (or the platform segments) would not have enough clearance to be removed from underneath the cask, in most situations, namely while moving sideways inside the Laydown Hall.

The single cubic spiral path, shown in Figure 3a), is the one which requires less building modifications and whose corresponding rescue clearance is larger.

### 3.3 Docking Ports of the HCB

This subsection covers the path between the HC corridor and the HC docking ports. The proposed cubic spiral path to the last docking port is depicted in Figure 4a). It is clear that with the current wall configuration, lateral and rear collision are unavoidable. As such, this is a location where building modification is definitely required. Actually, there is currently a considerable number of locations for which the rescue clearance space, shown in Figure 4b), is not enough, even for a 2-body platform (roughly iterations 15 to 30).



a) b)

Figure 4: Vehicle moving from the HC transport corridor to an HCB docking port: a) recommended smooth path and corresponding spanned area; b) available clearance space for rescue, along the path in a).

### 4. CONCLUSIONS AND OPEN POINTS

The vehicle design proposed in [5] is satisfactory from the standpoint of geometric feasibility. Even though geometric constraints are not satisfied for some critical locations along the path between the HCB and the VV, this is exclusively due to inappropriate building dimensions and could not be solved by modifications to the vehicle geometry and/or kinematic structure, assuming a rigid structure. Building modifications are required at some locations along the path, as mentioned in the text. Rescue vehicles will be needed for a small number of situations where building modification is not possible and, due to an aerocaster failure in a critical pose, neither clearance space is available for rescue by platform replacement nor the vehicle (cask + platform) is able to move by remote operator control. Under such a scenario, a rescue vehicle can provide air supply to drive the aerocasters during the time required to move the complete vehicle to a pose where rescue clearance allows platform removal.

Smooth paths which either do not require or require only minor building modifications were determined for all critical regions along the path, based on a cubic spirals method. Those paths do not require separate tracks to be followed by the vehicle drive units.

Manoeuvres may be a valid (or the only possible) alternative to cubic spiral paths in some situations. Should they be considered preferable, a more thorough study of spanned areas and rescue clearance should be made. Another alternative are separate paths for the two steering wheels. It may even be possible to find a smoothness criterion to design them systematically, but such a study should only be done if single paths cannot solve the problem.

## References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