D6.2 Manoeuvrability

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ABSTRACT

This task aims at establishing the effect of lengthening inland vessels on the manoeuvrability, including shallow water effects.

To determine the manoeuvring characteristics, standard zig-zag, combined turning circle / pull-out, evasive manoeuvres and crash stop simulations were conducted, considering the lengthening of typical inland vessels as reference (Hendrik and Rheinland), at different water depths and approach speeds.

The simulations were performed with SurSim, this is a program which simulates manoeuvring in the time domain. The typical output is a time trace of positions, angles, propulsion and rudder data. Based on the results of these simulations, trend of the effect of lengthening the inland vessels on the manoeuvrability, including shallow water effects, are depicted.

Based on the manoeuvring simulations, it could be concluded that the manoeuvring performances in terms of turning ability, directional stability, yaw checking ability, initial turning ability and stopping ability are not drastically affected by the lengthening of the vessel and therefore no practical measures should be needed. In the evasive manoeuvre simulations, the manoeuvring performances for Hendrik vessel are affected by the combination of lengthening of the vessel and shallow water effects: improvements on the rudder dimensions and characteristics can probably solve this issue.

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1 Introduction

This task aims at establishing the effect of lengthening inland vessels on the manoeuvrability, including shallow water effects.

To determine the manoeuvring characteristics, standard zig-zag, combined turning circle / pull-out, evasive manoeuvres and crash stop simulations were conducted, considering the lengthening of typical inland vessels as reference (Hendrik and Rheinland), at different water depths and approach speeds.

Simulations dedicated for the vessels Hendrik and Rheinland were performed by the University Dunarea de Jos of Galati (UGAL). The Maritime Research Institute Netherlands (MARIN) analysed the calculation results from UGAL. After analysing the calculation results from UGAL, it was concluded that the output values are unrealistic and no trends on the manoeuvrability could be found due to the lengthening. To be able to investigate the effect of lengthening on the manoeuvrability, MARIN performed additional simulations. For these calculations a generic inland ship was transformed to the same main dimensions as Hendrik and Rheinland.

This report presents the results of the manoeuvring calculations. The purpose of the manoeuvring calculations is to determine the yaw checking and course changing abilities, the turning ability, the directional stability, and the stopping ability of the vessel in order to depict the trend of the effect of lengthening the inland vessels on the manoeuvrability, including shallow water effects.

The results of the simulations are presented in the following sections and reference is made to the time histories and derived parameters. The results have been compared to relevant criteria concerning general manoeuvring characteristics.

2 Problem Definition

This task aims at establishing the effect of lengthening the inland vessels on the manoeuvrability, including shallow water effects.

Inland vessels have a need for very excellent manoeuvrability. Ships are sailing in areas with a heavy traffic density, shallow waters, in canals and locks.

Special requirements exist for inland vessels. The I.M.O. requirements are not valid (even if they are usually incorporated as reference), but the Central Commission for the Navigation of the Rhine (CCR) has for example special manoeuvring criteria for inland ships. Large convoys have to fulfil in addition criteria with respect to the swept path when turning. Rivers and canals are so small that large drift angles during turning should be avoided.

When a ship is designed, many aspects need to be considered, calculated, optimised and so on. This is necessary because the ship to be built has to fulfil specifications as stated in the building contract. In the building contract further reference is made to which classification society and other regulations, mostly from governmental regulating bodies, the ship has to comply with. On their turn the classification societies and other authorities all have their own rules and regulations the ship has further to comply with.

As far as “manoeuvring” is concerned, “requirements” are vague. In most building contracts only a general qualitative statement is made such as: the ship shall have good manoeuvring characteristics.
Reasons to require a good manoeuvrability originate from safety and economy.
Economy reasons are related to for example:

- The ability to perform un-assisted manoeuvres, so that no or less escort tugs are needed.
- Reduced rudder actions to keep the ship on a straight course so that the rudder and steering induced resistance on the long run is lower.
- Mission requirements for crabbing, dynamic tracking and dynamic positioning.

Safety reasons seem obvious but are:

- Ability to avoid collisions, ramming and grounding.
- Having control over the heading in all circumstances.

In a *qualitative way* a description of the demands that can be made of a steered vessel reads:

1. The ship must possess directionally stability. That is to say that the vessel needs to have the capability to sail in the desired direction, being the heading ψ. The drift angle β may not show large variations when sailing with a certain heading. The rudder angles necessary to compensate for the effects of disturbances (wind, waves) may not be too large.
2. It must be possible to change heading in a quick way while the overshoot must be small. Also the overshoot with regard to a desired path (width of path overshoot) must be within reasonable limits.

3. The vessel must be capable to perform a turning circle of which the dimensions in terms of advance, transfer and tactical diameter are not too large.
4. Given a certain amount of wind, the ship must be able to keep its heading without a large drift angle.
5. During accelerating and decelerating it must be possible to keep the vessel controlled.
6. At low speeds it must be possible to manoeuvre and to control its speed and direction without tug assistance up to a certain amount of wind, wave and current.
7. Being able to avoid collision and grounding. The reaction time of the ship must therefore be relatively quick.

Looking to the above terminology it may be clear that the demands are very subjective in nature. When an attempt is made to “translate” the above qualitative demands into quantitative and desired manoeuvring characteristics it might be obvious that such measures first of all strongly depend on the size of the vessel, not only on the size in terms of displacement or tonnage, but also on various hull parameters like L/B, B/T, block coefficient, etc.

The steering requirements become more intense when the ship is operating in areas with a high traffic density, and the collision risk is high.

Another factor that complicates a translation is the fact that the manoeuvring behaviour of a vessel changes when the loading condition is changed, especially trim has a large influence.

Furthermore, restrictions in the waterway influence the manoeuvring behaviour of the vessel, especially the water depth when becoming shallow. Such restrictions cause a change of the flow around the sailing vessel and hence, the hydrodynamic forces and moments, which act on the ship, will change.

Shallow water has a strong influence upon the inherent manoeuvring characteristics of ships. When manoeuvring is concerned a water depth to draft ratio of $WD/T \ll 3$ is considered to be shallow. The effects upon the manoeuvring characteristics become visible at $WD/T = 3$ and become more pronounced as the ratio becomes smaller.

Therefore, when a vessel fulfils certain requirements for a given condition and is judged to have “good” (qualitative) manoeuvring characteristics it might happen that at other conditions the vessel behaves poorly.

It is difficult for naval architects to determine which ships are well manoeuvrable or poorly manoeuvrable. The only persons really having a feeling which ships are to consider “good” and “bad” are probably pilots and experienced captains. In order to establish objective criteria, it is needed to evaluate the subjective opinion of the pilots with regard to ships and detract the needed information from them. Some examples of this are found in the literature. In Japan, the pilots association made a list of ships frequently entering Japanese harbours and summed the comments on “badly” manoeuvrable ships. If one examines such a list, various reasons are given why pilots distinguish good and bad ships. After all, good manoeuvrability is a compromise between turning ability and course keeping ability.

Up till now inherent manoeuvring characteristics are the most common way to express a qualitative judgement upon the manoeuvring behaviour with terms like good, average, bad manoeuvring characteristics. By no means the statement that the ship will manoeuvre safely during all circumstances or similar statements can be derived from this.
The inherent characteristics are derived from:

- Turning circle manoeuvres.
- Zig-zag manoeuvres.
- Evasive manoeuvres.
- Stopping manoeuvres.

These manoeuvres are often referred to as definitive manoeuvres because a class of manoeuvres is described solely to obtain numerical values of specific handling qualities.

These manoeuvres are simulated considering the lengthening of typical inland vessels as reference, at different water depths and approach speeds.

Based on the results of these simulations, trend of the effect of lengthening the inland vessels on the manoeuvrability, including shallow water effects, are depicted.

3 Technical approach

In the following table the main dimensions of the reference vessel (Hendrik and Rheinland) as used in the simulations are shown.

Table 3.1: Ships main dimensions

	Hendrik			Rheinland		
	Original ship	*First lengthening*	*Second lengthening*	*Original ship*	*First lengthening*	*Second lengthening*
Length between perpendiculars, L_{PP}(m)	69.60	81.34	94.03	56.65	62.03	67.88
Breadth, B (m)	8.60	8.60	8.60	6.34	6.34	6.34
Draught, T (m)	2.95	2.95	2.95	2.429	2.429	2.429
Depth (m)	3.000	3.000	3.000	2.5	2.5	2.5
Displacement (t)	1360	1664	1988	724	816	908

The results of the manoeuvring calculations, performed by the University Dunarea de Jos of Galati, are presented in tabular and graphical form in the appendix. After analysis these calculation results were found to be unrealistic and were not used in the further investigation in to the effect of lengthening on the manoeuvrability.

The manoeuvring calculations performed by MARIN were conducted using an adapted version of the latest release of SurSim. The theory in the simulation program is based on cross flow drag theory, published amongst others by Hooft[1] and Hooft and Nienhuis[2] and Hooft and Quadvlieg[3]. Details of the hull form are incorporated in the modelling of the forces on the hull during manoeuvring.

It should be noted that:

- due to effects and interactions that may be omitted in the simulation, discrepancies might exist between the calculation results and actual experimental or full scale data; further model experiments should therefore increase the accuracy of the predicted manoeuvring behaviour of the ship.
- some information of main dimension of ships, propellers, and steering system of the reference vessels (Hendrik and Rheinland) were missing: these values were evaluated based on experience, MARIN manoeuvring database or estimation.

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[1] Hooft, J.P. "The cross flow drag on a manoeuvring ship". *Ocean Engineering*, Vol. 21, No. 3, pp. 329-342, 1994.

[2] Hooft, J.P. and Nienhuis, U.; “The prediction of the ship’s manoeuvrability in the Design Stage”, *1994 Trans. SNAME*, Vol. 102. New York, 1995.

[3] Hooft, J.P. and Quadvlieg, F.H.H.A.; “Non-linear hydrodynamic forces derived from segmented model tests”, *MARSIM 1996*, ISBN 9054108312.

- the IMO criteria are incorporated in the current analysis as reference, and moreover:
    - The criteria apply to manoeuvres when approached at a speed of at least 90% of the ship's speed corresponding to 85% of the maximum engine output. The lower speed limit of the vessel under consideration conform the IMO resolution was unknown.
    - The standard manoeuvres should be performed without the use of any manoeuvring aids, which are not continuously and readily available in normal operation.
    - Maximum of 35 deg helm permissible at the test speed can be used to verify compliancy with the turning circle criteria.
    - All manoeuvres should be performed in deep unrestricted water in a calm environment at the full load condition.

SurSim is a program which simulates manoeuvring in the time domain. The typical output is a time trace of positions, angles, propulsion and rudder data.

All simulations were carried out for a loading condition. The simulations were carried out on different approach speeds.

In order to investigate the manoeuvring performances as a function of the length of the vessel and the water depth, alternative lengthening and water depths were considered in the simulations.

During this simulation programme the following simulations were conducted:

Table 3.2: Review of the simulations (Hendrik)

Zig-zag manoeuvres

Ship length [m]	Water depth [m]	Water depth – draft ratio [-]	V_0 [km/h]	δ [deg]	ψ [deg]
69.98, 82, 95	3.50	1.2	10	10	10
				20	20
			13	10	10
				20	20
	5.00	1.7	10	10	10
				20	20
			13	10	10
				20	20
	20.0	6.8	10	10	10
				20	20
			13	10	10
				20	20

Combined turning circle / pull-out manoeuvres

Ship length [m]	Water depth [m]		V_0 [km/h]	δ [deg]	δ_{PO} [deg]
69.98, 82, 95	3.50	1.2	10	35	0
			13	35	0
	5.00	1.7	10	35	0
			13	35	0
	20.0	6.8	10	35	0
			13	35	0

Evasive manoeuvres

Ship length [m]	Water depth [m]	Water depth – draft ratio [-]	V_0 [km/h]	δ [deg]	r [deg/min]
69.98, 82, 95	3.50	1.2	13	20	20
				45	28
	5.00	1.7	13	20	20
				45	28
	20.0	6.8	13	20	20
				45	28

Crash stop calculations

Ship length [m]	Water depth [m]		V_0 [km/h]	δ [deg]	ψ [deg]
69.98, 82, 95	3.50	1.2	10	0	-
			13	0	-
	5.00	1.7	10	0	-
			13	0	-
	20.0	6.8	10	0	-
			13	0	-

In these tables, V_0 is the approach speed, δ is the steering angle, δ_{PO} is the pull-out steering angle, ψ the yaw-checking angle, and r is the yaw rate of turn.

Table 3.3: Review of the simulations (Rheinland)

Zig-zag manoeuvres					
Ship length [m]	Water depth [m]	Water depth – draft ratio [-]	V_0 [km/h]	δ [deg]	ψ [deg]
56.65, 62.03, 67.88	3.50	1.2	10	10	10
				20	20
			13	10	10
				20	20
	5.00	1.7	10	10	10
				20	20
			13	10	10
				20	20
	20.0	6.8	10	10	10
				20	20
			13	10	10
				20	20
Combined turning circle / pull-out manoeuvres					
Ship length [m]	Water depth [m]		V_0 [km/h]	δ [deg]	δ_{PO} [deg]
56.65, 62.03, 67.88	3.50	1.2	10	35	0
			13	35	0
	5.00	1.7	10	35	0
			13	35	0
	20.0	6.8	10	35	0
			13	35	0
Evasive manoeuvres					
Ship length [m]	Water depth [m]	Water depth – draft ratio [-]	V_0 [km/h]	δ [deg]	r [deg/min]
56.65, 62.03, 67.88	3.50	1.2	13	20	20
				45	28
	5.00	1.7	13	20	20
				45	28
	20.0	6.8	13	20	20
				45	28
Crash stop calculations					
Ship length [m]	Water depth [m]		V_0 [km/h]	δ [deg]	ψ [deg]
56.65, 62.03, 67.88	3.50	1.2	10	0	-
			13	0	-
	5.00	1.7	10	0	-
			13	0	-
	20.0	6.8	10	0	-
			13	0	-

In these tables, V_0 is the approach speed, δ is the steering angle, δ_{PO} is the pull-out steering angle, ψ the yaw-checking angle, and r is the yaw rate of turn.

The nomenclature, sign definitions and units of the results are presented in section 6.6. The calculation procedures for conducting the zig-zag and combined turning circle pull-out calculations and the derived parameters are described respectively in section 6.7 and 6.8.

4 Results and Achievements

The results of the experiments are presented in the following sections.

4.1 Design requirements and criteria

In order to judge the manoeuvring characteristics of the vessel under consideration reference is made to the following criteria.

The standardised manoeuvring derivatives have been verified where relevant with the criteria as posed by the IMO in their resolution MSC. 137(76), see section 6.5. By their resolution, the IMO posed manoeuvring criteria applicable to ships with a length of 100 m. or more or carrying dangerous goods. These IMO standards are not applicable to the vessel under consideration, but are incorporated in the current analysis as reference, but it has to be noticed that:

- The criteria apply to manoeuvres when approached at a speed of at least 90% of the ship's speed corresponding to 85% of the maximum engine output. The lower speed limit of the vessel under consideration conform the IMO resolution was unknown.
- The standard manoeuvres should be performed without the use of any manoeuvring aids, which are not continuously and readily available in normal operation.
- Maximum or 35 degree helm permissible at the test speed can be used verifying compliancy with the turning circle criteria. In the performed simulations 35 degree helm was selected.
- All manoeuvres should be performed in deep unrestricted water in a calm environment at the full load condition.

Table 41: CCR criteria

	Required rotational speed r1 = r3 [°/min]		Time limits t_4 [s] in deep and shallow water		
	δ = 20°	δ = 45°	1,2≤W_D/T≤1,4	1,4<W_D/T≤2	W_D/T>2
All motor vessel	20°/min	28°/min	150 s	110 s	110 s

4.2 Combined turning circle / pull-out manoeuvre

The resulting derived parameters of the combined turning circle and pull-out simulations are presented in the figures in the appendix, section 6.1. The procedure for conducting combined turning circle / pull-out simulations is described in section 6.8.

With the results of the turning circle calculations, the turning ability and the directional stability of the vessel can be derived.

The turning ability is the measure of the ability to turn the ship using hard-over steering. Moreover, the motion behaviour in a turn is directly available, such as maximum and continuous roll angle and speed reduction. The turning ability is measured by means of the advance at 90° change of heading, and the tactical diameter defined by the transfer at 180° change of heading. Analysis of the final turning diameter is of additional interest.

The directional stability is often displayed by the rate of turn-steering angle curve, indicating the amount of directional stability or directional instability of the ship. At a constant position of the steering system the ship is defined to be directional stable if after some short disturbance it will resume the original manoeuvre without any use of the steering means. The ship is unstable if a turning rate will exist after this disturbance.

As it can be seen from the simulations that the manoeuvring performances in terms of turning ability and directional stability are not drastically affected by the lengthening of the vessel or shallow water manoeuvring, and therefore no practical measure (as for instance the bow rudders) should be needed.

The decrease in the turning ability performances in shallow water can be improved by using power bursts.

4.3 Zig-zag manoeuvre

The resulting derived parameters of the zig-zag manoeuvre simulations are presented in the figures in the appendix, section 6.2. In an overview the results are presented as well as the compliance to the reference criteria is verified. The procedure for conducting zig-zag manoeuvre simulations is described in section 6.7.

With the results of these calculations, the yaw checking ability (or the course checking behaviour), and the initial turning ability (or the level of course changing), as a measure of the steering device effectiveness, can be derived.

According to the IMO the yaw checking ability of the ship is a measure of the response to counter-rudder applied in a certain state of turning, such as the heading overshoot reached before the yawing tendency has been cancelled by the counter-rudder in a standard zig-zag manoeuvre.

The initial turning ability is defined by the change-of-heading response to a moderate helm, in terms of heading deviation per unit distance sailed or in terms of the distance covered before realizing a certain heading deviation (such as the “time to second execute” demonstrated when entering the zig-zag manoeuvre).

As it can be seen, the manoeuvring performances in terms of yaw checking ability and initial turning ability are not drastically affected by the lengthening of the vessel or shallow water manoeuvring, and therefore no practical measure (as for instance the bow rudders) should be needed.

The decrease in the initial turning ability performances in shallow water can be improved by decreasing the approach speed.

4.4 *Evasive manoeuvre*

The resulting derived parameters of the evasive manoeuvre simulations are presented in the figures in the appendix, section 6.3.

As it can be seen from the figures, the manoeuvring performances for Hendrik vessel are affected by the combination of lengthening of the vessel and shallow water effects: improvements on the rudder dimensions and characteristics can solve this issue.

Instead, the manoeuvring performances for Rheinland are not drastically affected by the lengthening of the vessel, and therefore no practical measure (as for instance the bow rudders) should be needed in this case.

4.5 *Stopping (crash stop manoeuvre)*

The resulting derived parameters of the stopping simulations are presented in the figures in the appendix, section 6.4.

With the results of the crash stop calculations, the stopping ability of the vessel can be derived.

The stopping ability is measured by the “track reach” and “time to dead in water” realized in a stop engine-full astern manoeuvre performed after a steady approach at full speed.

As it can be seen, the manoeuvring performances in terms of stopping ability are not drastically affected by the lengthening of the vessel or shallow water manoeuvring, and therefore no practical measure (as for instance the bow rudders) should be needed.

5 Conclusion / outlook to next steps

Based on the manoeuvring simulations programme, the following conclusions can be drawn regarding the manoeuvring behaviour of the ship.

- The manoeuvring performances in terms of turning ability and directional stability are not drastically affected by the lengthening of the vessel and therefore no practical measures (as for instance the bow rudders) should be needed. The shallow water effect is similar for all lengthening: decreasing water depth has the same effect for the elongated and the shorter vessels. Obviously, the decrease of water depth causes increased turning circle dimension. Therefore the decrease in the turning ability performances in shallow water can be improved by decreasing the approach speed.

- The manoeuvring performances in terms of yaw checking ability and initial turning ability are not drastically affected by the lengthening of the vessel, and therefore no practical measure (as for instance the bow rudders) should be needed. The decrease in the initial turning ability performances in shallow water can be improved by decreasing the approach speed.

- In the evasive manoeuvre simulations, the manoeuvring performances for Hendrik vessel are affected by the combination of lengthening of the vessel and shallow water effects: improvements on the rudder dimensions and characteristics can probably solve this issue. Instead, the manoeuvring performances for Rheinland are not drastically affected by the lengthening of the vessel, and therefore no practical measure (as for instance the bow rudders) should be needed in this case.

- The manoeuvring performances in terms of stopping ability are not drastically affected by the lengthening of the vessel, and therefore no practical measure (as for instance the bow rudders) should be needed.

6 ANNEXES

6.1 Results combined turning circle / pull-out manoeuvre

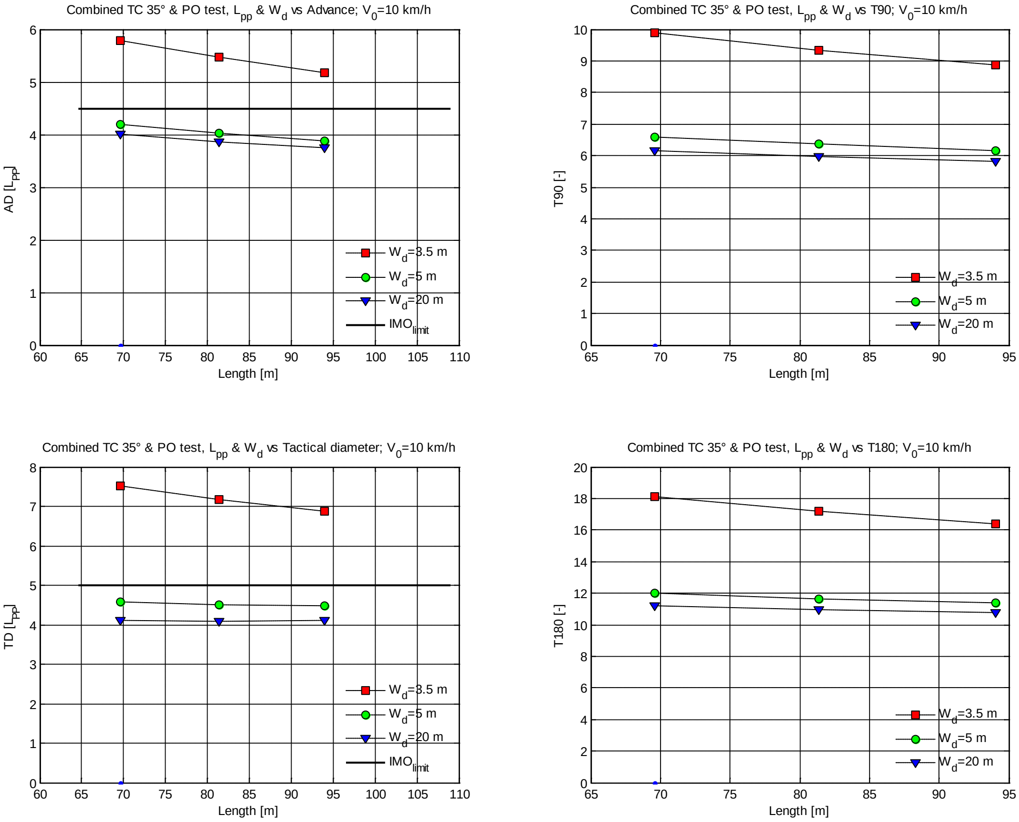


Figure 1: Hendrik turning circle manoeuvre performance (10 km/h)

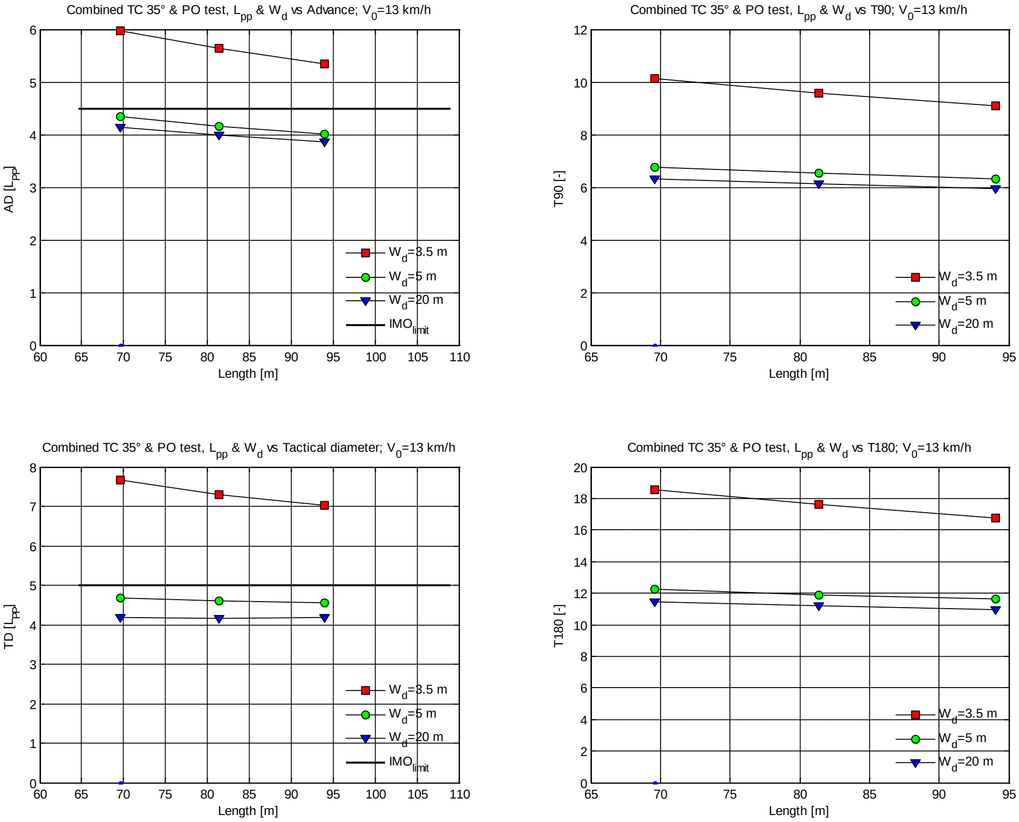


Figure 2: Hendrik turning circle manoeuvre performance (13 km/h)

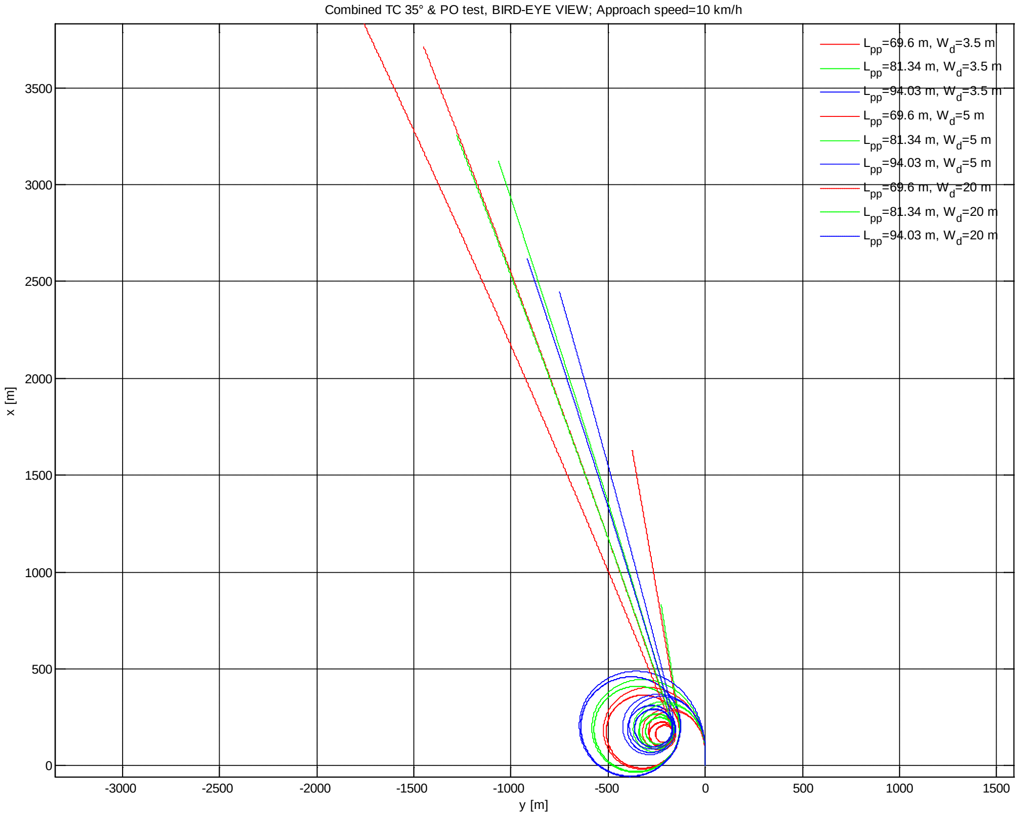


Figure 3: Hendrik combined turning circle & pull-out manoeuvre bird-eye views (10 km/h)

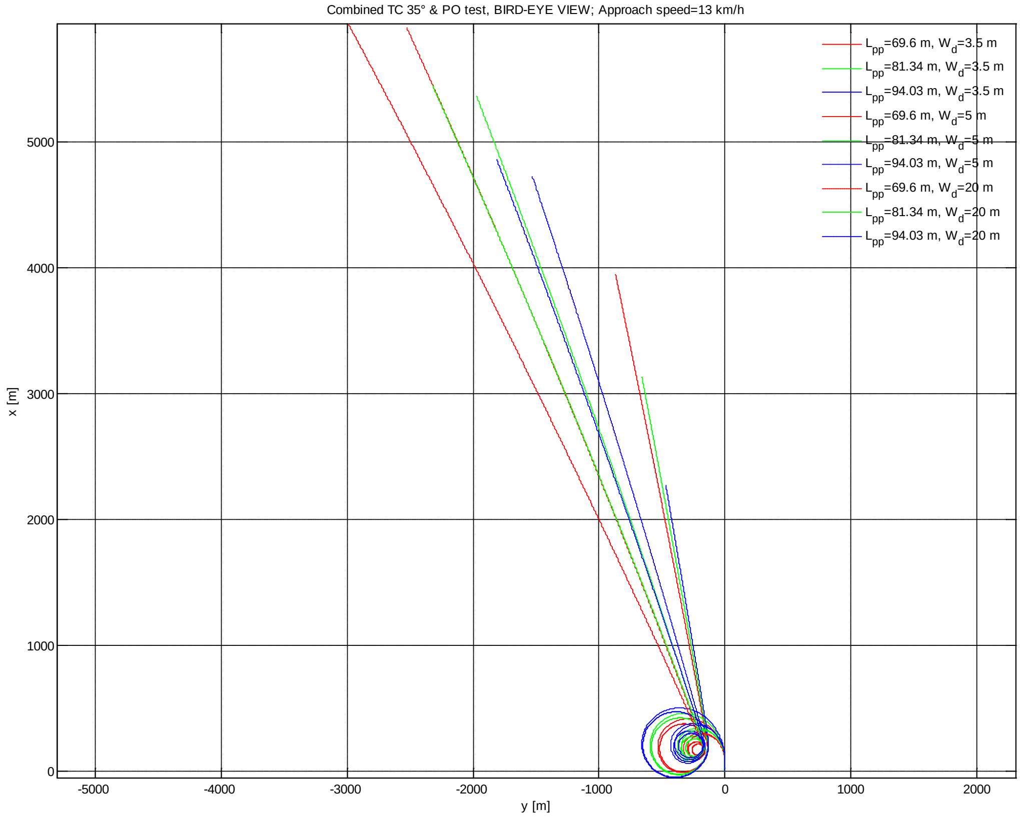


Figure 4: Hendrik combined turning circle & pull-out manoeuvre bird-eye views (13 km/h)

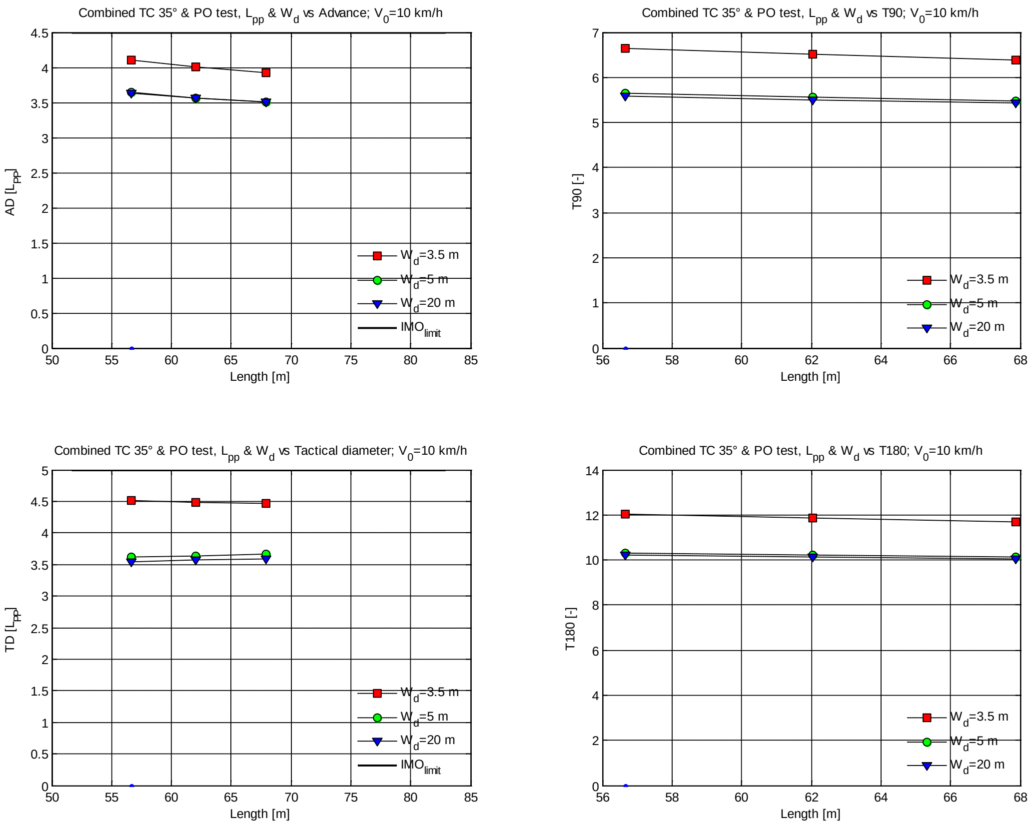


Figure 5: Rheinland turning circle performance (10 km/h)

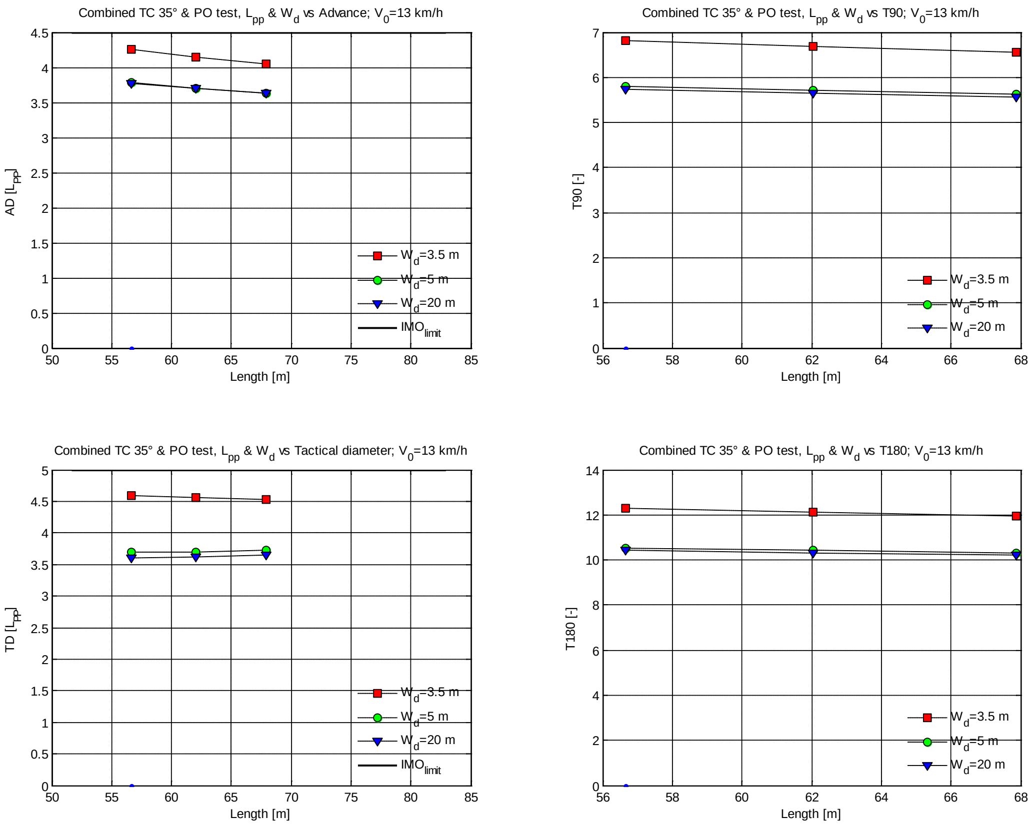


Figure 6: Rheinland turning circle performance (13 km/h)

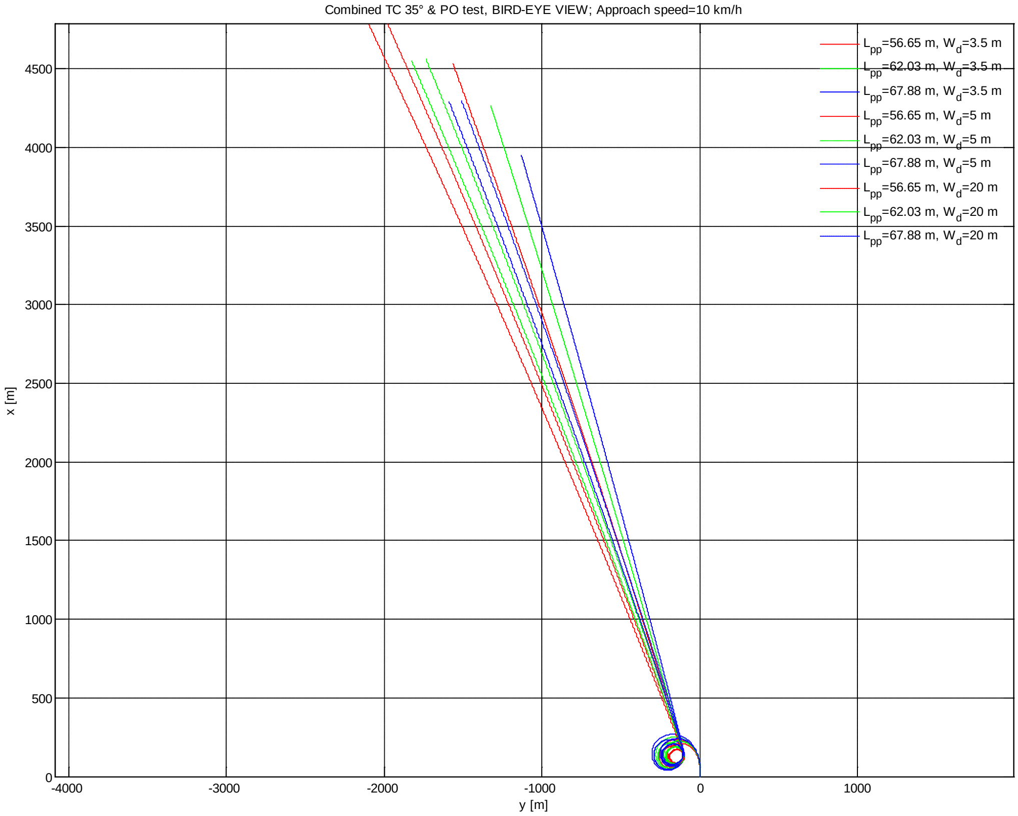


Figure 7: Rheinland combined turning circle & pull-out manoeuvre bird-eye views (10 km/h)

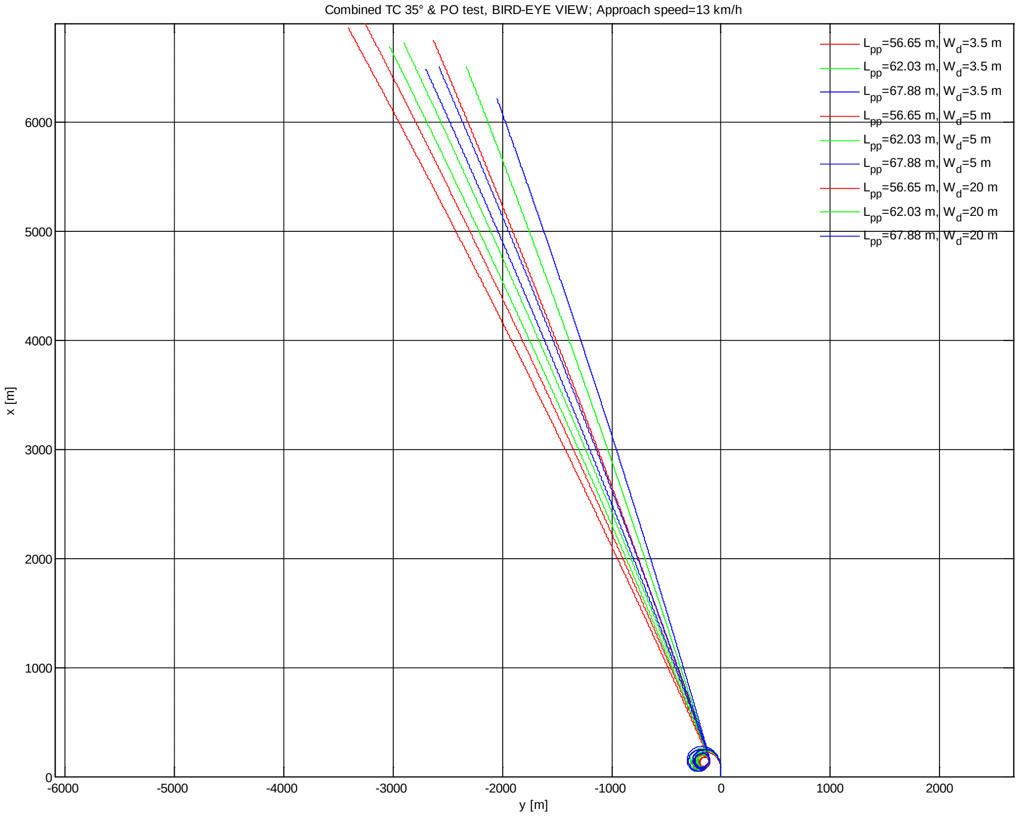


Figure 8: Rheinland combined turning circle & pull-out manoeuvre bird-eye views (13 km/h)

6.2 Results zig-zag manoeuvre

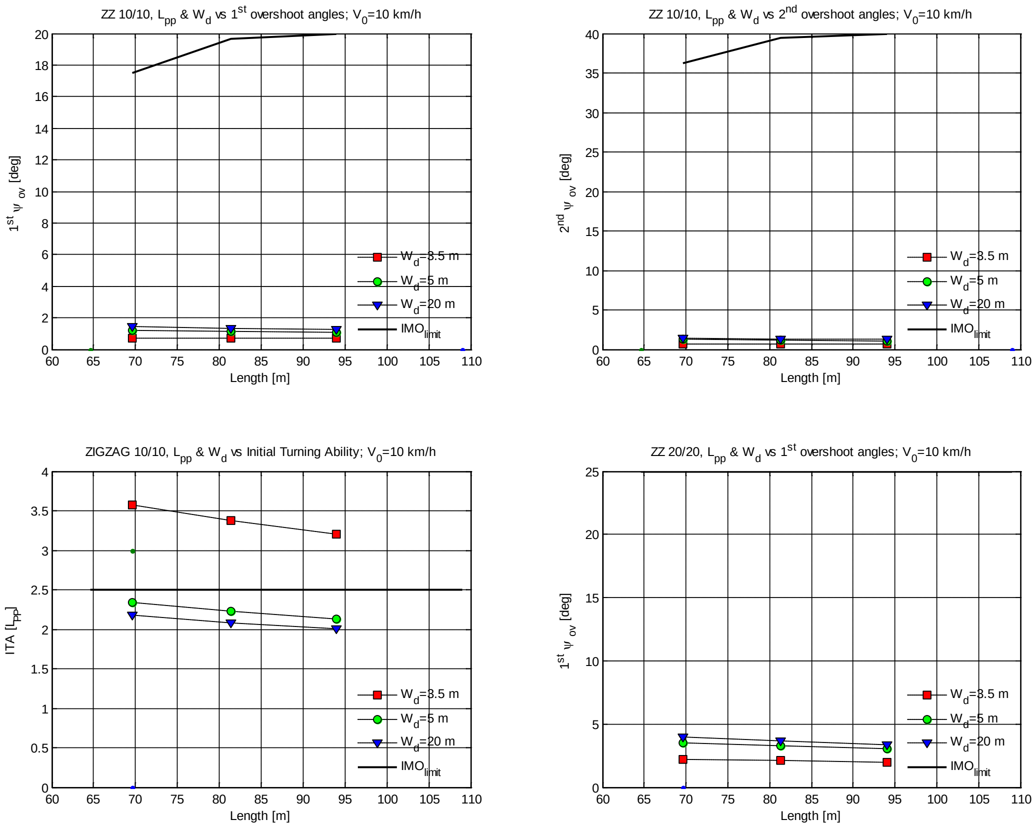


Figure 9: Hendrik zigzag manoeuvre performance (10 km/h)

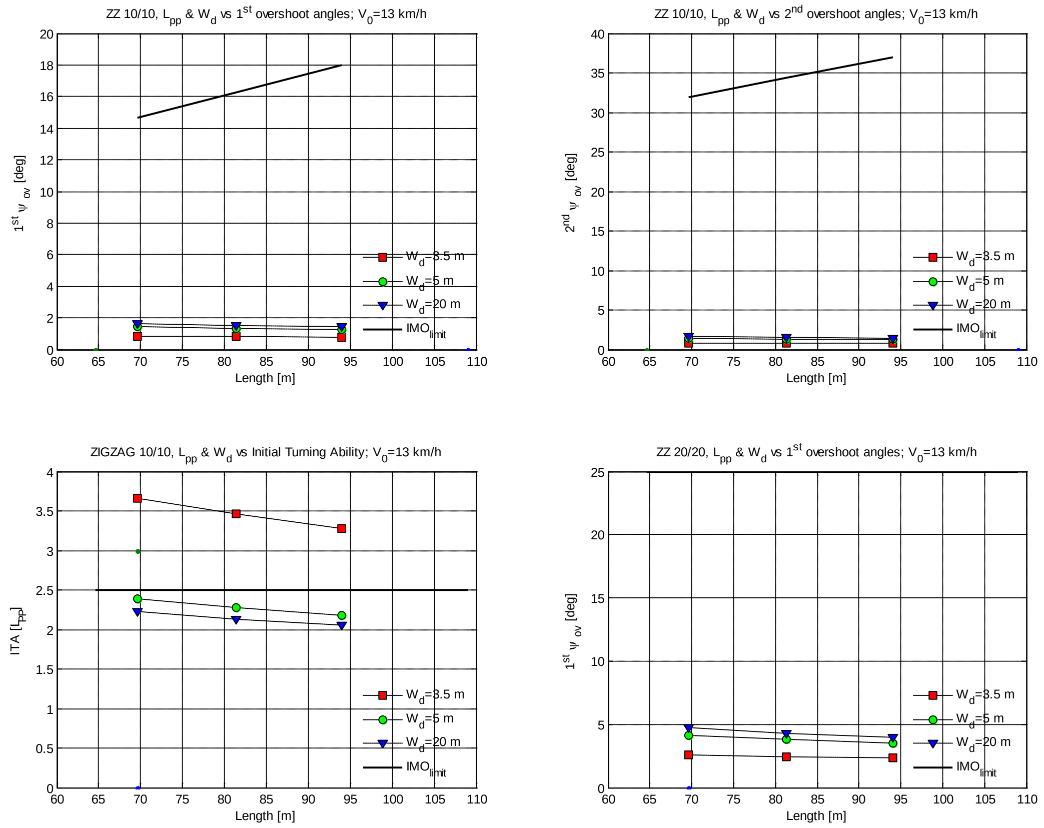


Figure 10: Hendrik zigzag manoeuvre performance (13 km/h)

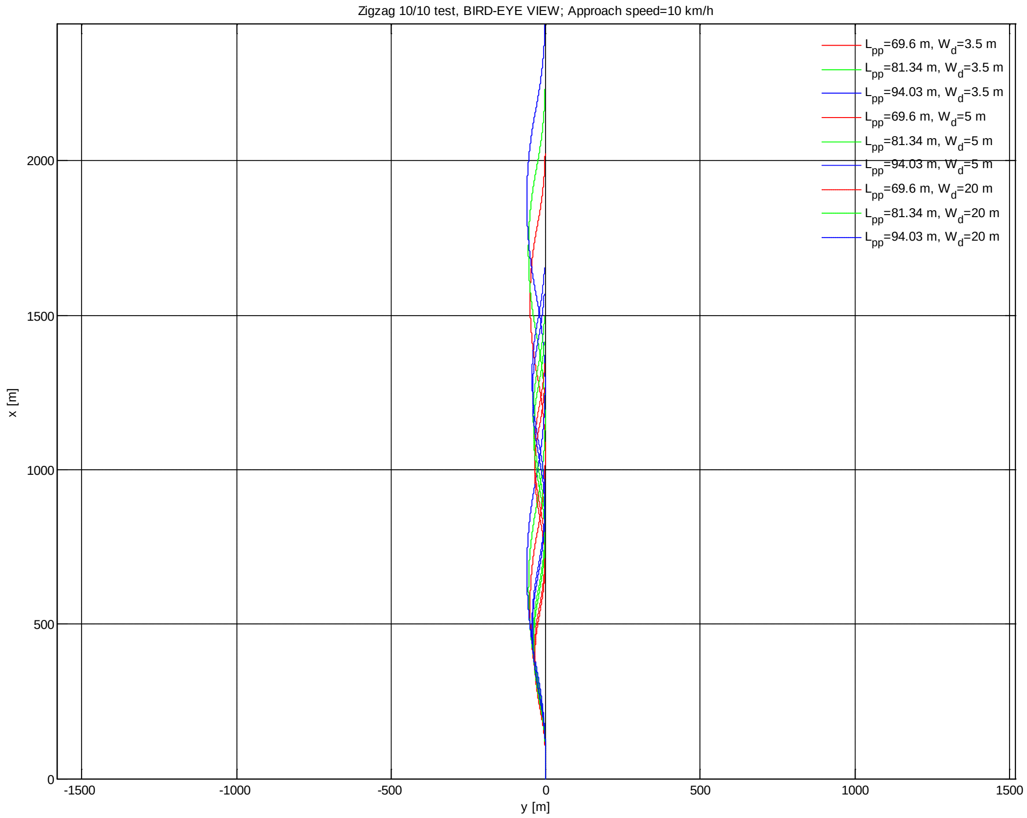


Figure 11: Hendrik zigzag 10/10 manoeuvre bird-eye view (10 km/h)

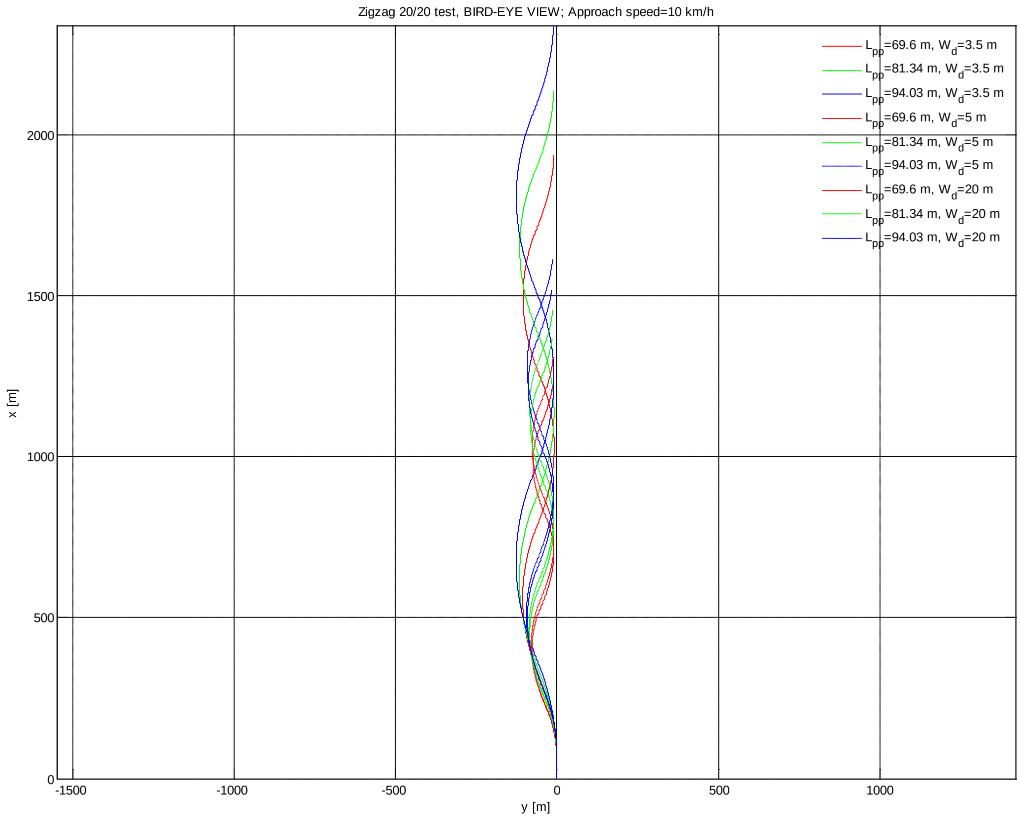


Figure 12: Hendrik zigzag 20/20 manoeuvre bird-eye view (10 km/h)

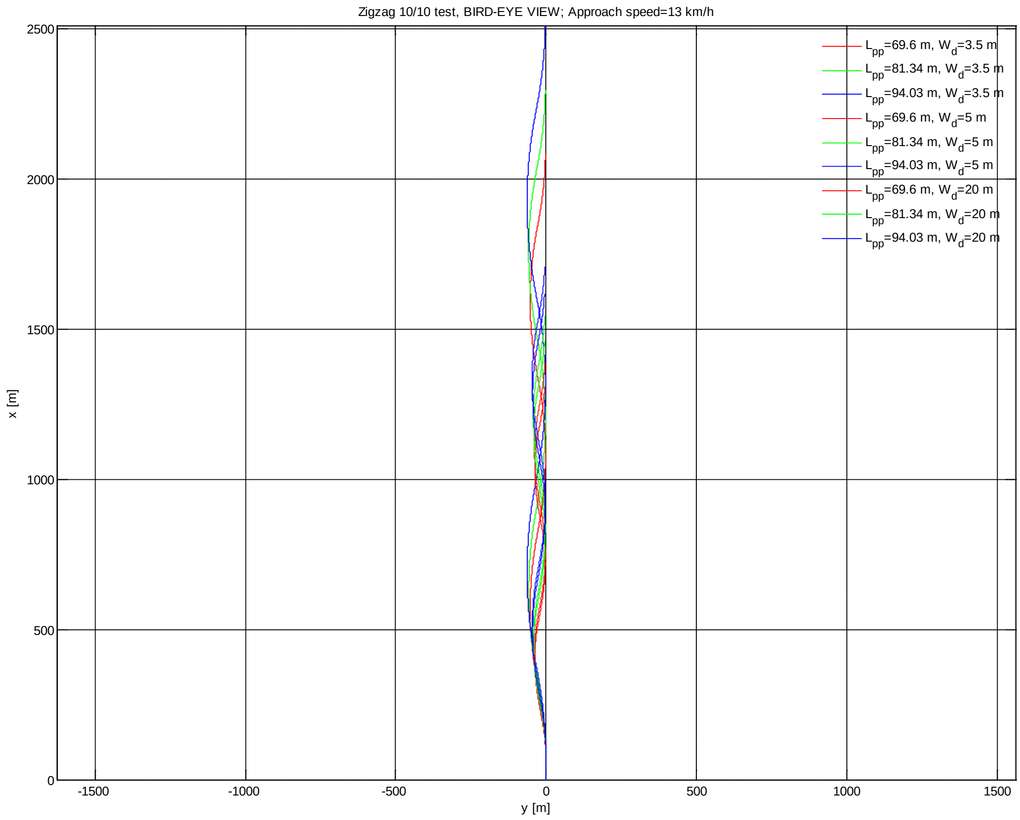


Figure 13: Hendrik zigzag 10/10 manoeuvre bird-eye view (13 km/h)

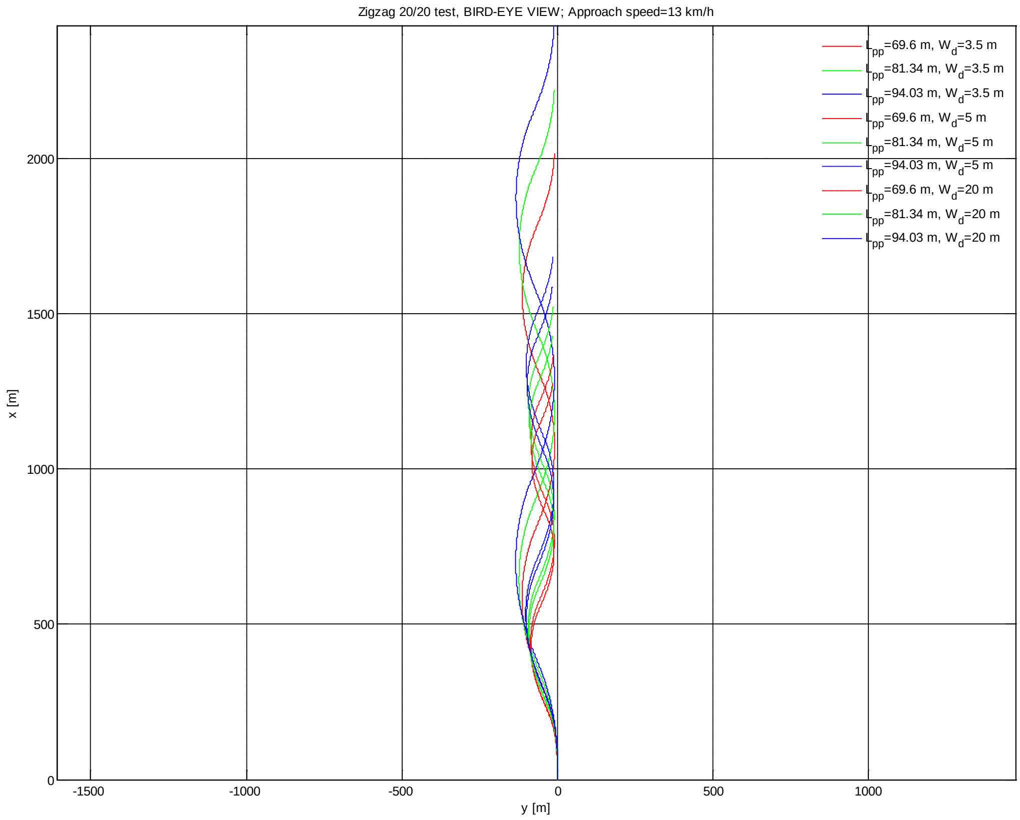


Figure 14: Hendrik zigzag 20/20 manoeuvre bird-eye view (13 km/h)

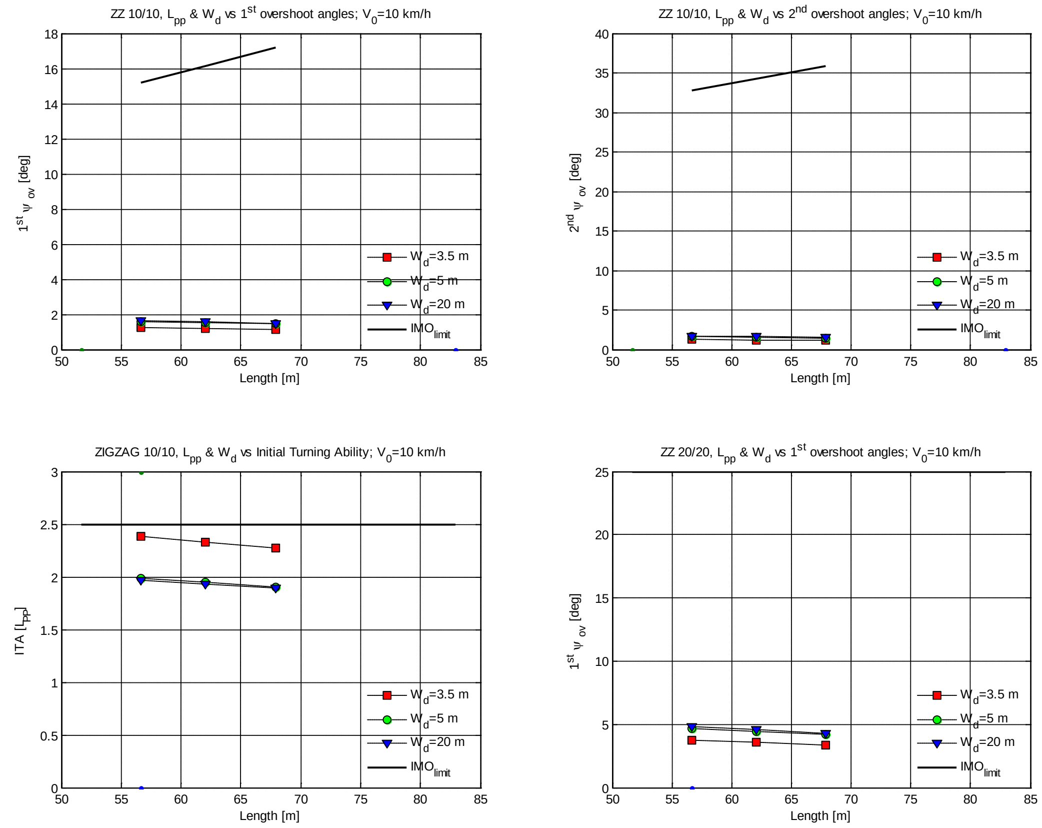


Figure 15: Rheinland zigzag manoeuvre performance (10 km/h)

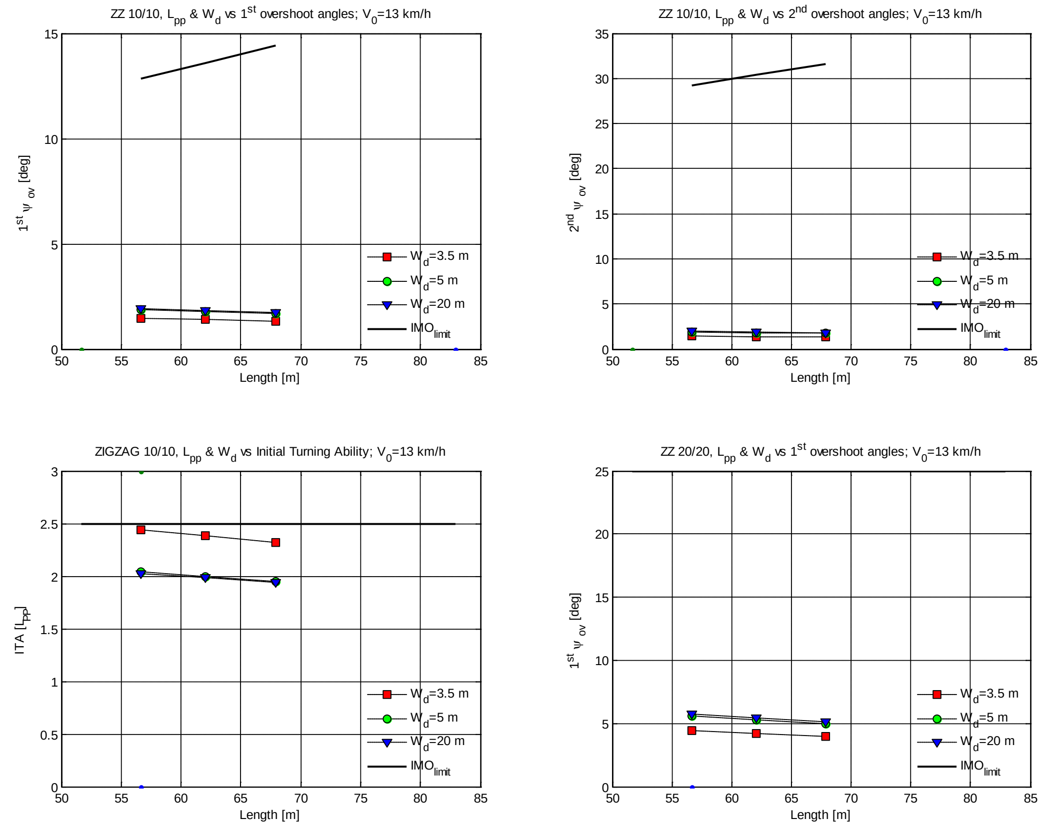


Figure 16: Rheinland zigzag manoeuvre performance (13 km/h)

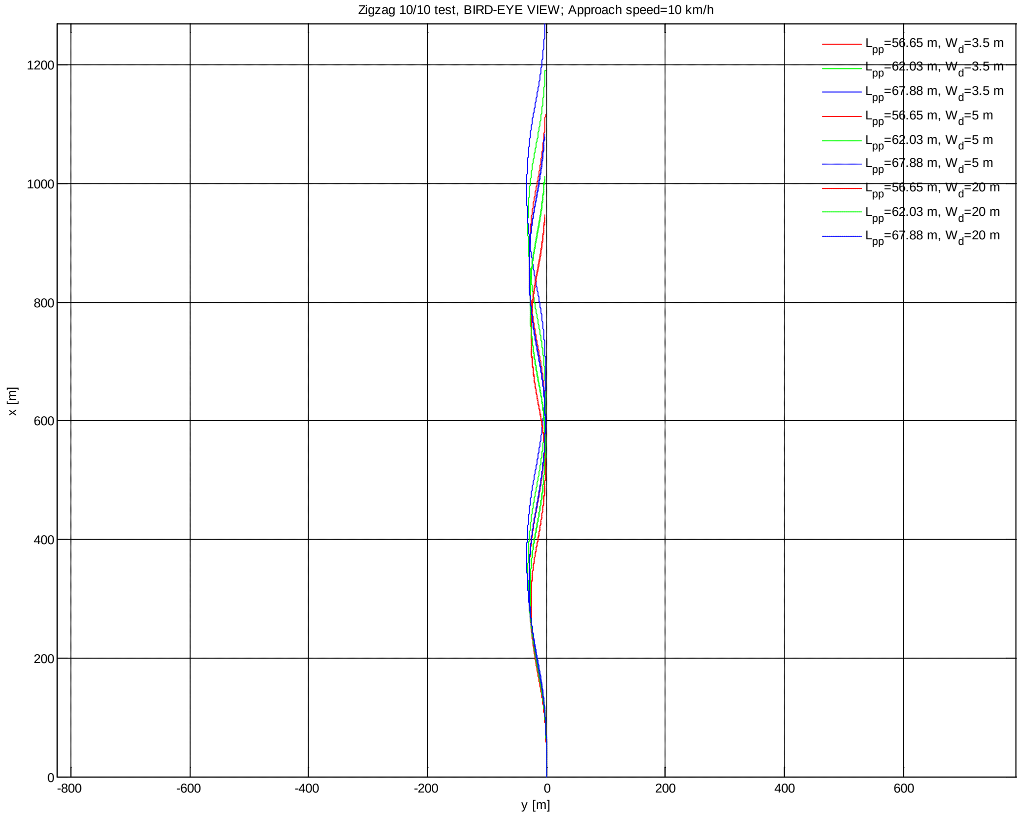


Figure 17: Rheinland zigzag 10/10 manoeuvre bird-eye views (10 km/h)

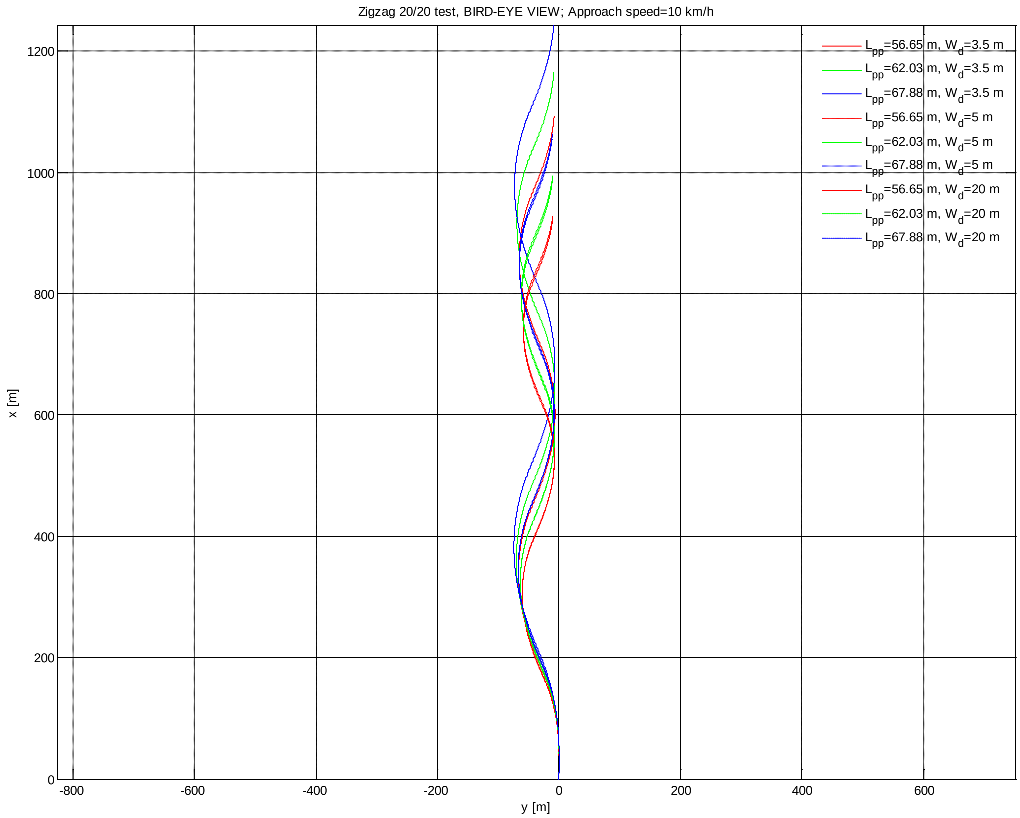


Figure 18: Rheinland zigzag 20/20 manoeuvre bird-eye views (10 km/h)

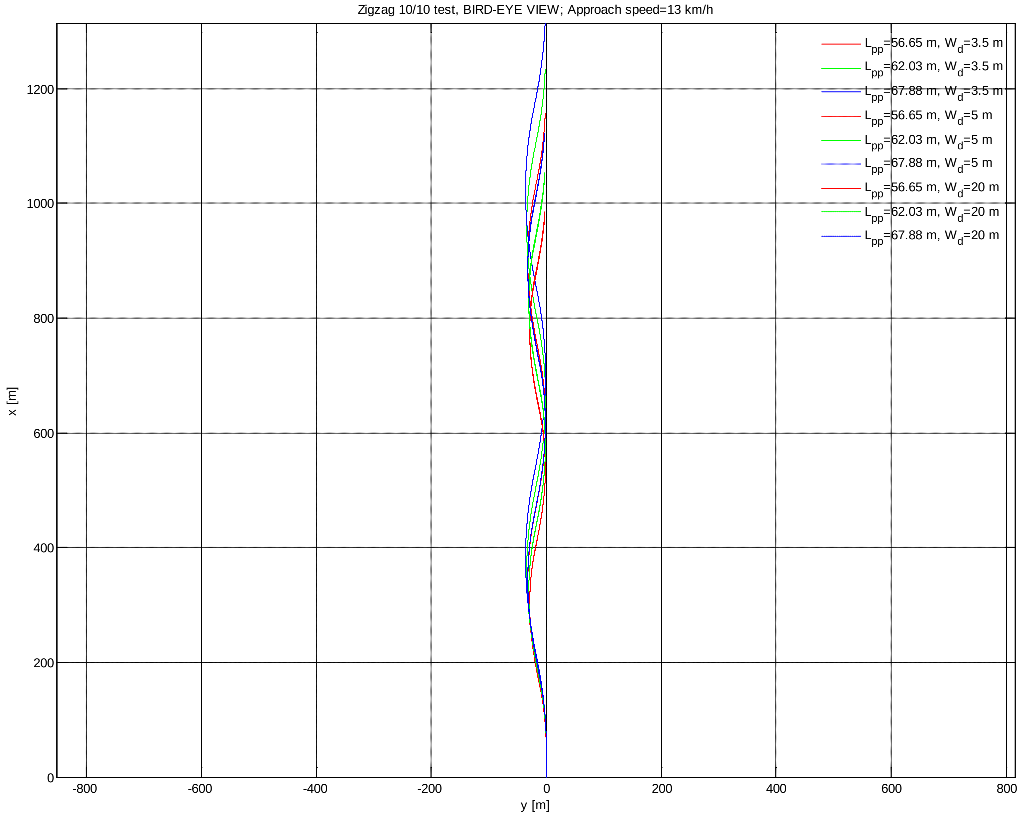


Figure 19: Rheinland zigzag 10/10 manoeuvre bird-eye views (13 km/h)

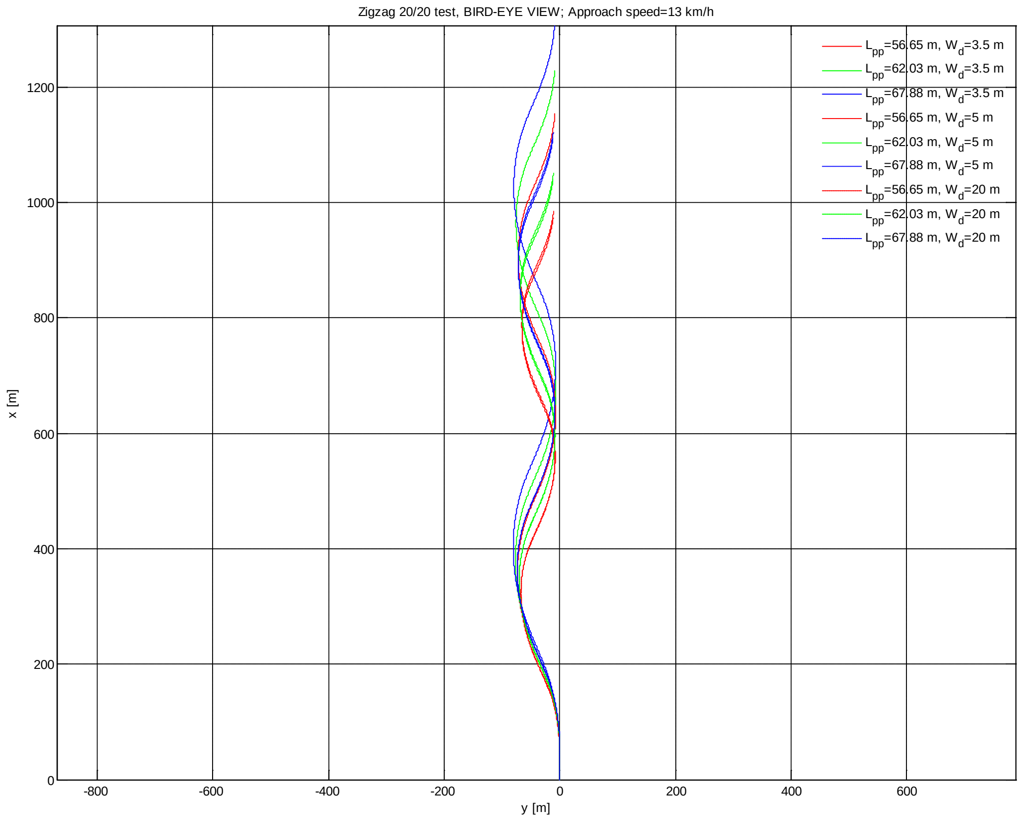


Figure 20: Rheinland zigzag 20/20 manoeuvre bird-eye views (13 km/h)

6.3 Results evasive manoeuvre

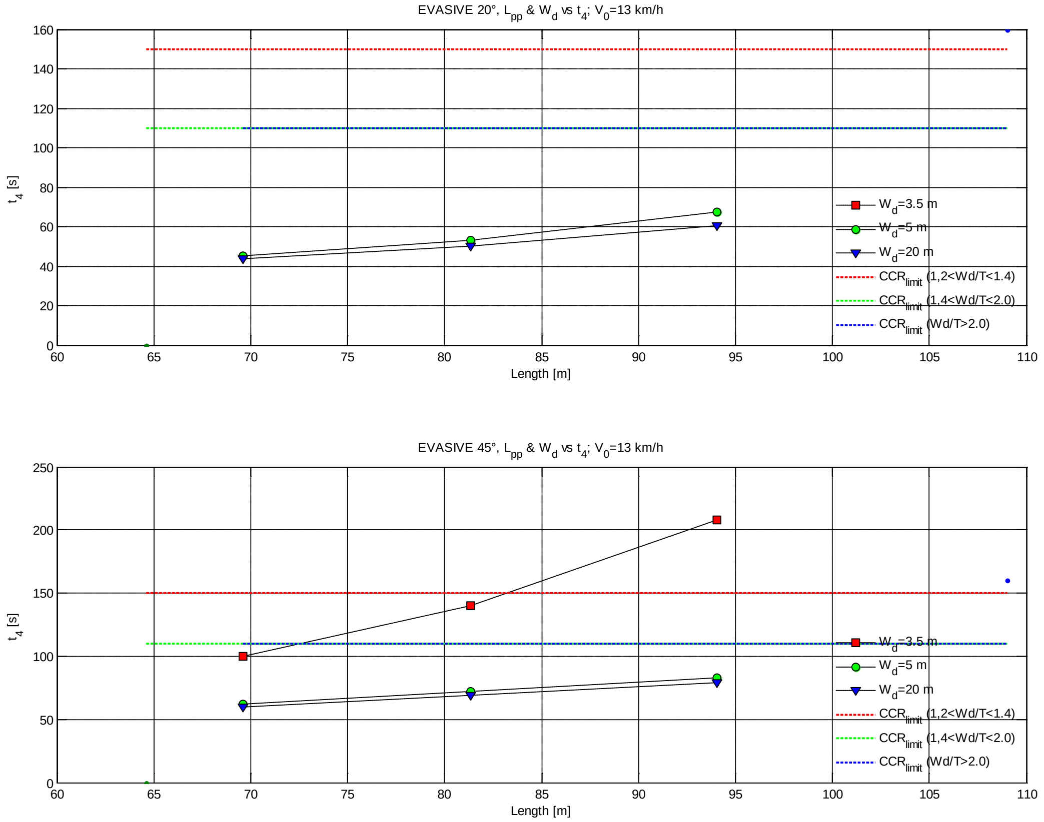
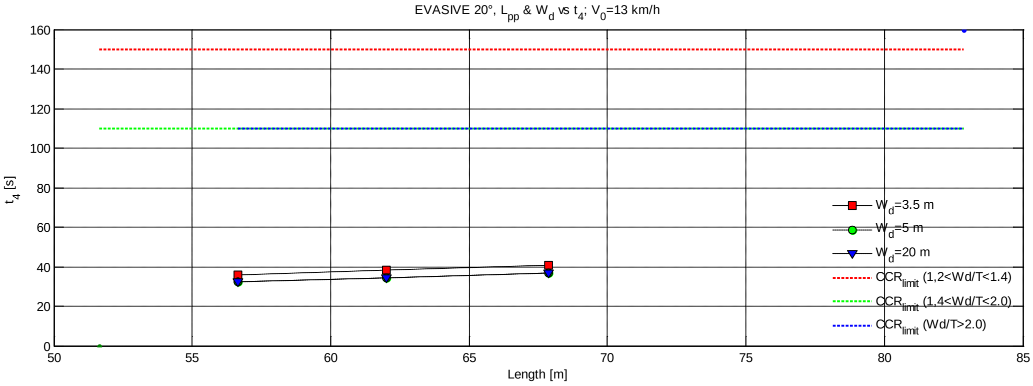


Figure 21: Hendrik evasive manoeuvre performance (13 km/h)



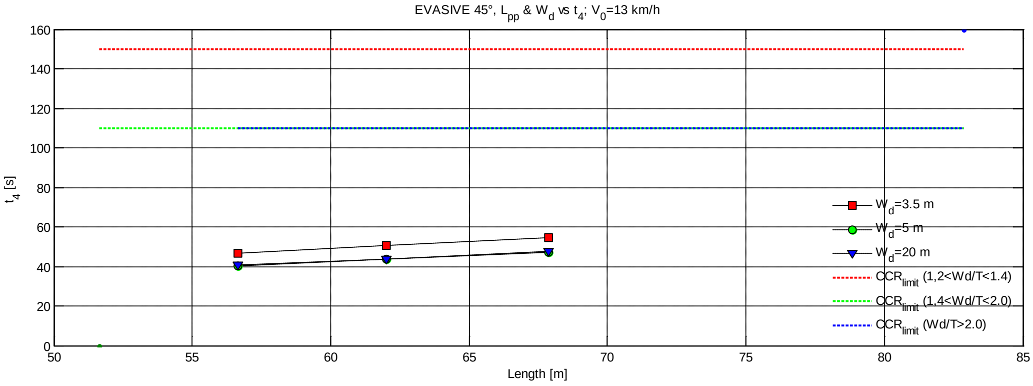


Figure 22: Rheinland evasive manoeuvre performance (13 km/h)

6.4 Results stopping calculations (crash stop manoeuvre)

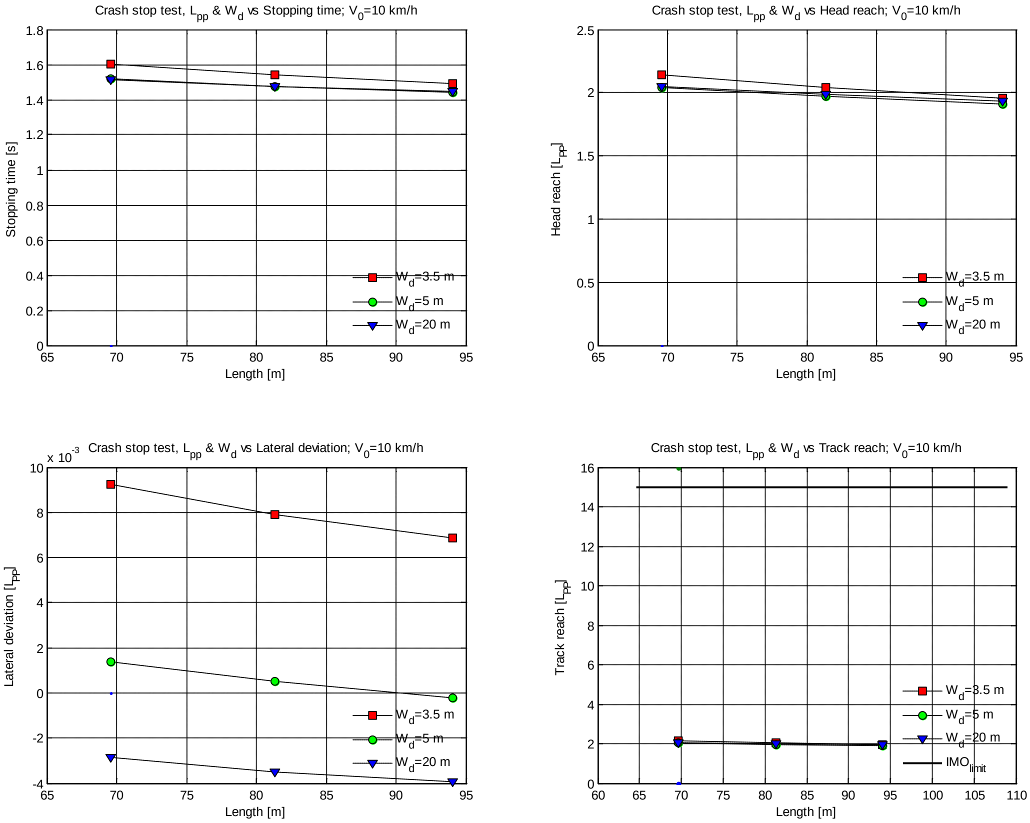


Figure 23: Hendrik crash stop calculation performance (10 km/h)

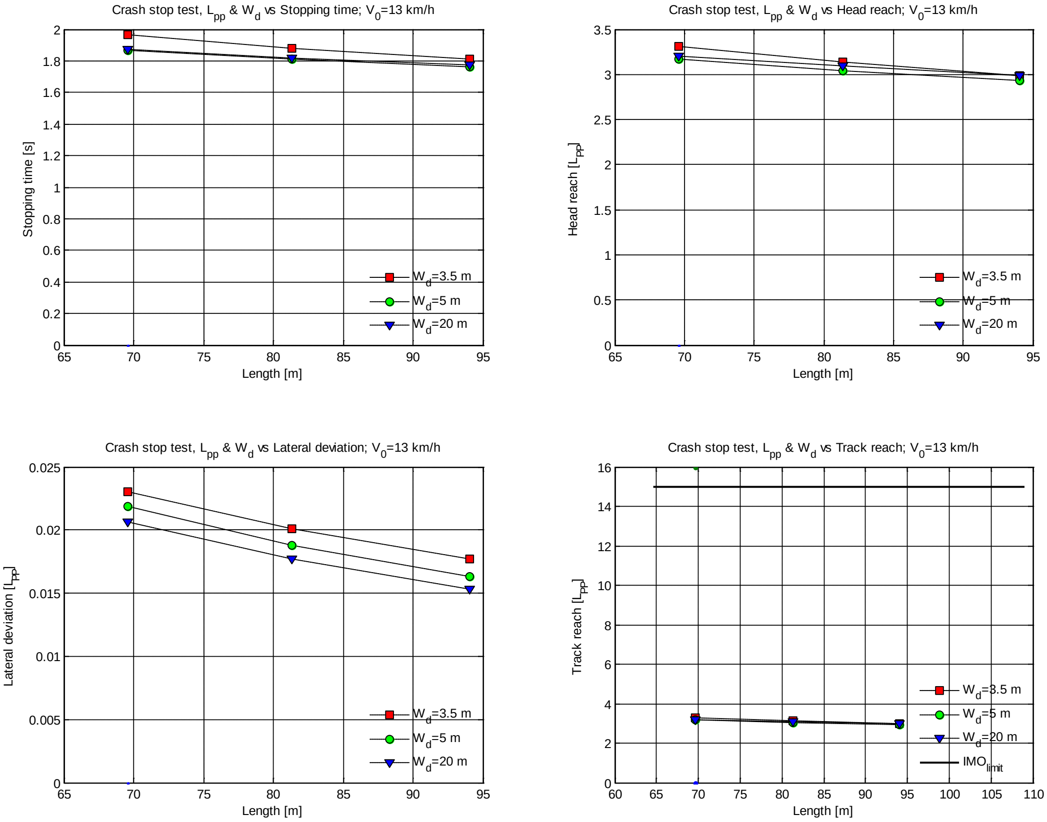


Figure 24: Hendrik crash stop calculation performance (13 km/h)

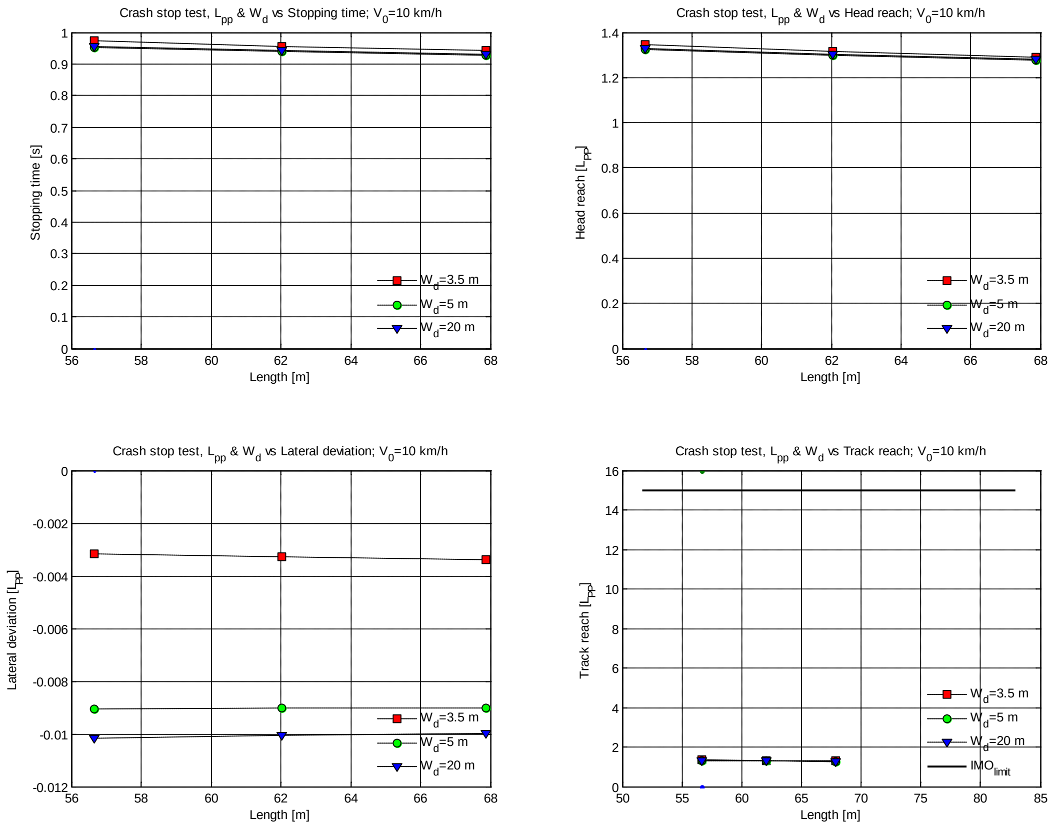


Figure 25: Rheinland crash stop calculation performance (10 km/h)

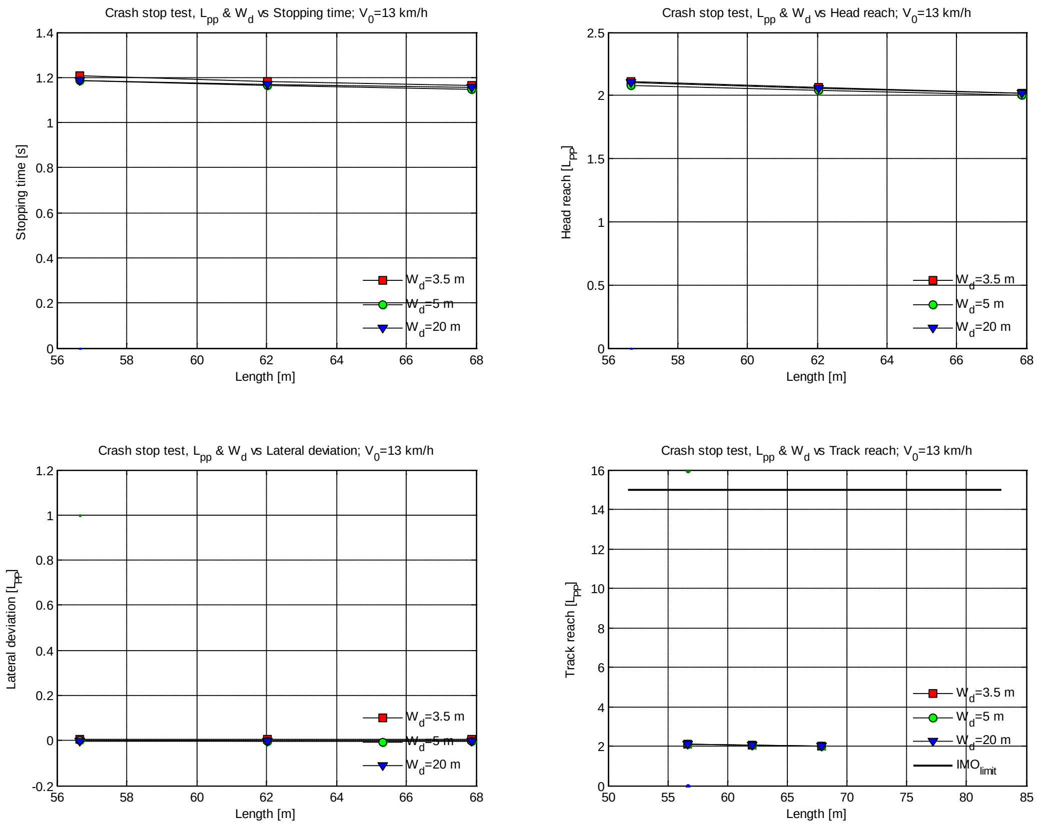


Figure 26: Rheinland crash stop calculation performance (13 km/h)

6.5 *IMO Resolution MSC 137(76)*

INTERNATIONAL MARITIME ORGANIZATION

MSC 76/23/Add.1

ANNEX 6

RESOLUTION MSC.137(76)
(adopted on 4 December 2002)

STANDARDS FOR SHIP MANOEUVRABILITY

THE MARITIME SAFETY COMMITTEE,

RECALLING Article 28(b) of the Convention on the International Maritime Organisation concerning the functions of the Committee,

RECALLING ALSO that by resolution A.751(18) the Assembly approved Interim Standards for ship manoeuvrability (the Interim standards), whereby Governments were recommended to encourage those responsible for the design, construction, repair and operation of ships to apply the Interim Standards and invited to collect data obtained by the application of the Interim Standards and report them to the Organisation,

RECALLING FURTHER that by circular MSC/Circ.1053 the Committee approved Explanatory notes to the Standards for ship manoeuvrability, to provide Administrations with specific guidance so that adequate data may be collected by the Organisation on the manoeuvrability of ships,

RECOGNIZING the manoeuvring capability of ships to be an important contribution to the safety of navigation,

BELIEVING that the development and implementation of standards for ship manoeuvrability, particularly for large ships and ships carrying dangerous goods in bulk, will improve maritime safety and enhance marine environmental protection,

HAVING CONSIDERED the recommendation made by the Sub-Committee on Ship Design and Equipment at its forty-fifth session,

1. ADOPTS the Standards for ship manoeuvrability, the text of which is set out in the Annex to the present resolution;

2. INVITES Governments to encourage those responsible for the design, construction, repair and operation of ships to apply the Standards to ships constructed on or after 1 January 2004;

3. RESOLVES that the provisions annexed to the present resolution supersede the provisions annexed to resolution A.751(18).

STANDARDS FOR SHIP MANOEUVRABILITY

1 PRINCIPLES

1.1 The Standards for ship manoeuvrability (the Standards) should be used to evaluate the manoeuvring performance of ships and to assist those responsible for the design, construction, repair and operation of ships.

1.2 It should be noted that the Standards were developed for ships with traditional propulsion and steering systems (e.g. shaft driven ships with conventional rudders). Therefore, the Standards and methods for establishing compliance may be periodically reviewed and updated by the Organisation, as appropriate, taking into account new technologies, research and development, and the results of experience with the present Standards.

2 GENERAL

2.1 The Standards contained in this document are based on the understanding that the manoeuvrability of ships can be evaluated from the characteristics of conventional trial manoeuvres. The following two methods can be used to demonstrate compliance with these Standards:

.1 scale model tests and/or computer predictions using mathematical models can be performed to predict compliance at the design stage. In this case full-scale trials should be conducted to validate these results. The ship should then be considered to meet these Standards regardless of full-scale trial results, except where the Administration determines that the prediction efforts were substandard and/or the ship performance is in substantial disagreement with these Standards; and

.2 the compliance with the Standards can be demonstrated based on the results of the full-scale trials conducted in accordance with the Standards. If a ship is found in substantial disagreement with the Standards, then the Administration should take remedial action, as appropriate.

3 APPLICATION

3.1 Notwithstanding the points raised in paragraph 1.2 above, the Standards should be applied to ships of all rudder and propulsion types, of 100 m in length and over, and chemical tankers and gas carriers regardless of the length.

3.2 In the event that the ships referred to in paragraph 3.1 above undergo repairs, alterations or modifications, which, in the opinion of the Administration, may influence their manoeuvrability characteristics, the continued compliance with the Standards should be verified.

3.3 Whenever other ships, originally not subject to the Standards, undergo repairs, alterations or modifications, which, in the opinion of the Administration, are of such an extent that the ship may be considered to be a new ship, then that ship should comply with these Standards. Otherwise, if the repairs, alterations and modifications, in the opinion of the Administration, may influence the manoeuvrability characteristics, it should be demonstrated that these characteristics do not lead to any deterioration of the manoeuvrability of the ship.

3.4 The Standards should not be applied to high-speed craft as defined in the relevant Code.

4 DEFINITIONS

4.1 Geometry of the ship

4.1.1 *Length (L)* is the length measured between the aft and forward perpendiculars.

4.1.2 *Midship point* is the point on the centreline of a ship midway between the aft and forward perpendiculars.

4.1.3 *Draught* (T_A) is the draught at the aft perpendicular.

4.1.4 *Draught* (T_F) is the draught at the forward perpendicular.

4.1.5 *Mean draught* (T_M) is defined as $T_M = (T_A + T_F)/2$.

4.1.6 *Trim* ($\square$) is defined as $\square = (T_A - T_F)$.

4.1.7 Δ is the full load displacement of the ship (tonnes).

4.2 Standard manoeuvres and associated terminology

Standard manoeuvres and associated terminology are as defined below:

.1 The test speed (V) used in the Standards is a speed of at least 90% of the ship's speed corresponding to 85% of the maximum engine output.

.2 Turning circle manoeuvre is the manoeuvre to be performed to both starboard and port with 35° rudder angle or the maximum rudder angle permissible at the test speed, following a steady approach with zero yaw rate.

.3 Advance is the distance travelled in the direction of the original course by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 90° from the original course.

.4 Tactical diameter is the distance travelled by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 180° from the original course. It is measured in a direction perpendicular to the original heading of the ship.

.5 Zig-zag test is the manoeuvre where a known amount of helm is applied alternately to either side when a known heading deviation from the original heading is reached.

.6 The 10°/10° zig-zag test is performed by turning the rudder alternately by 10° to either side following a heading deviation of 10° from the original heading in accordance with the following procedure:

.1 after a steady approach with zero yaw rate, the rudder is put over to 10° to starboard or port (first execute);

.2 when the heading has changed to 10° off the original heading, the rudder is reversed to 10° to port or starboard (second execute); and

.3 after the rudder has been turned to port/starboard, the ship will continue turning in the original direction with decreasing turning rate.
In response to the rudder, the ship should then turn to port/starboard. When the ship has reached a heading of 10° to port/starboard of the original course the rudder is again reversed to 10° to starboard/port (third execute).

.7 The first overshoot angle is the additional heading deviation experienced in the zig-zag test following the second execute.

.8 The second overshoot angle is the additional heading deviation experienced in the zig-zag test following the third execute.

.9 The 20°/20° zig-zag test is performed using the procedure given in paragraph 4.2.6 above using 20° rudder angles and 20° change of heading, instead of 10° rudder angles and 10° change of heading, respectively.

.10 Full astern stopping test determines the track reach of a ship from the time an order for full astern is given until the ship stops in the water.

.11 Track reach is the distance along the path described by the midship point of a ship measured from the position at which an order for full astern is given to the position at which the ship stops in the water.

5 STANDARDS

5.1 The standard manoeuvres should be performed without the use of any manoeuvring aids, which are not continuously and readily available in normal operation.

5.2 Conditions at which the standards apply

In order to evaluate the performance of a ship, manoeuvring trials should be conducted to both port and starboard and at conditions specified below:

.1 deep, unrestricted water;

.2 calm environment;

.3 full load (summer load line draught), even keel condition; and

.4 steady approach at the test speed.

5.3 Criteria[4]

The manoeuvrability of the ship is considered satisfactory if the following criteria are complied with:

.1 Turning ability

The advance should not exceed 4.5 ship lengths (L) and the tactical diameter should not exceed 5 ship lengths in the turning circle manoeuvre.

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[4] For ships with non-conventional steering and propulsion systems, the Administration may permit the use of comparative steering angles to the rudder angles specified by this Standard.

.2 Initial turning ability

With the application of 10° rudder angle to port/starboard, the ship should not have travelled more than 2.5 ship lengths by the time the heading has changed by 10° from the original heading.

.3 Yaw-checking and course-keeping abilities

.1 The value of the first overshoot angle in the 10°/10° zig-zag test should not exceed:

.1 10° if L/V is less than 10 s;

.2 20° if L/V is 30 s or more; and

.3 (5 + 1/2(L/V)) degrees if L/V is 10 s or more, but less than 30 s,

where L and V are expressed in m and m/s, respectively.

.2 The value of the second overshoot angle in the 10°/10° zig-zag test should not exceed:

.1 25°, if L/V is less than 10 s;

.2 40°, if L/V is 30 s or more; and

.3 (17.5 + 0.75(L/V))°, if L/V is 10 s or more, but less than 30 s.

.3 The value of the first overshoot angle in the 20°/20° zig-zag test should not exceed 25°.

.4 Stopping ability

The track reach in the full astern stopping test should not exceed 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.

6 ADDITIONAL CONSIDERATIONS

6.1 In case the standard trials are conducted at a condition different from those specified in paragraph 5.2.3, necessary corrections should be made in accordance with the guidelines contained in the Explanatory notes to the Standards for ship manoeuvrability, developed by the Organisation.[5]

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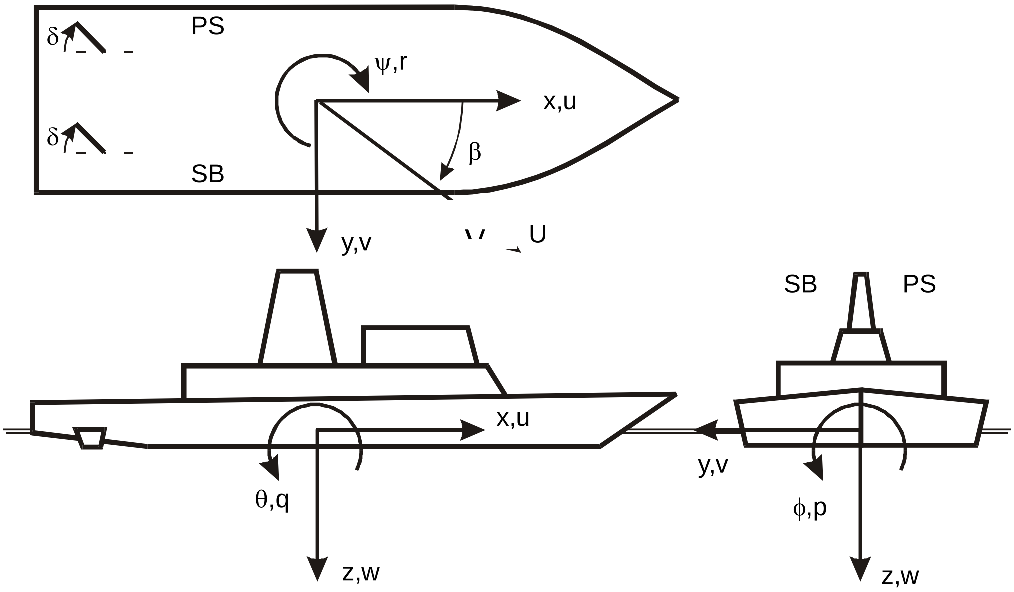
[5] Refer to MSC/Circ.1053 on Explanatory notes to the Standards for ship manoeuvrability.

6.2 Where standard manoeuvres indicate dynamic instability, alternative tests may be conducted to define the degree of instability. Guidelines for alternative tests such as a spiral test or pull-out manoeuvre are included in the Explanatory notes to the Standards for ship manoeuvrability, referred to in paragraph 6.1 above.

6.6 *MARIN sign convention for manoeuvring calculations*

In this report the following definitions and sign conventions are used:

DESIGNATION	SYMBOL	UNIT	POSITIVE FOR
Time	t	s	-
Linear scale ratio	□	-	-
Froude number $F_n = \frac{V}{\sqrt{g \cdot L_{pp}}}$	F_n	-	forward speed
Ship speed in origin $V = \sqrt{u^2 + v^2}$	V	kn, m/s	forward speed
Reference point of ship, origin	O	-	intersection ordinate 10, centre line plane and waterline
Longitudinal position	x	m	forward of O
Transverse position	y	m	SB of O
Vertical position	z	m	downward from O
Roll angle	□	deg	SB down
Pitch angle	□	deg	bow up
Yaw or course angle (heading)	□	deg	bow to SB
Velocity / acceleration along body x-axis	u	m/s	directed forward
Velocity / acceleration along body y-axis	v	m/s	directed to SB
Velocity / acceleration along body z-axis	w	m/s	directed downward
Roll rate / acceleration	p	deg/s	turning SB down
Pitch rate / acceleration	q	deg/s	turning bow up
Yaw rate / acceleration	r	deg/s	turning bow to SB
Notation of the derivatives of velocities and rates	e.g. $\dot{r}$	deg/s^2	
Drift angle $\beta = \arctan\left(\frac{v}{u}\right)$	□	deg	positive v
Dimensionless rate of turn $\gamma = \frac{r \cdot L_{pp}}{V}$	□	-	turning bow to SB



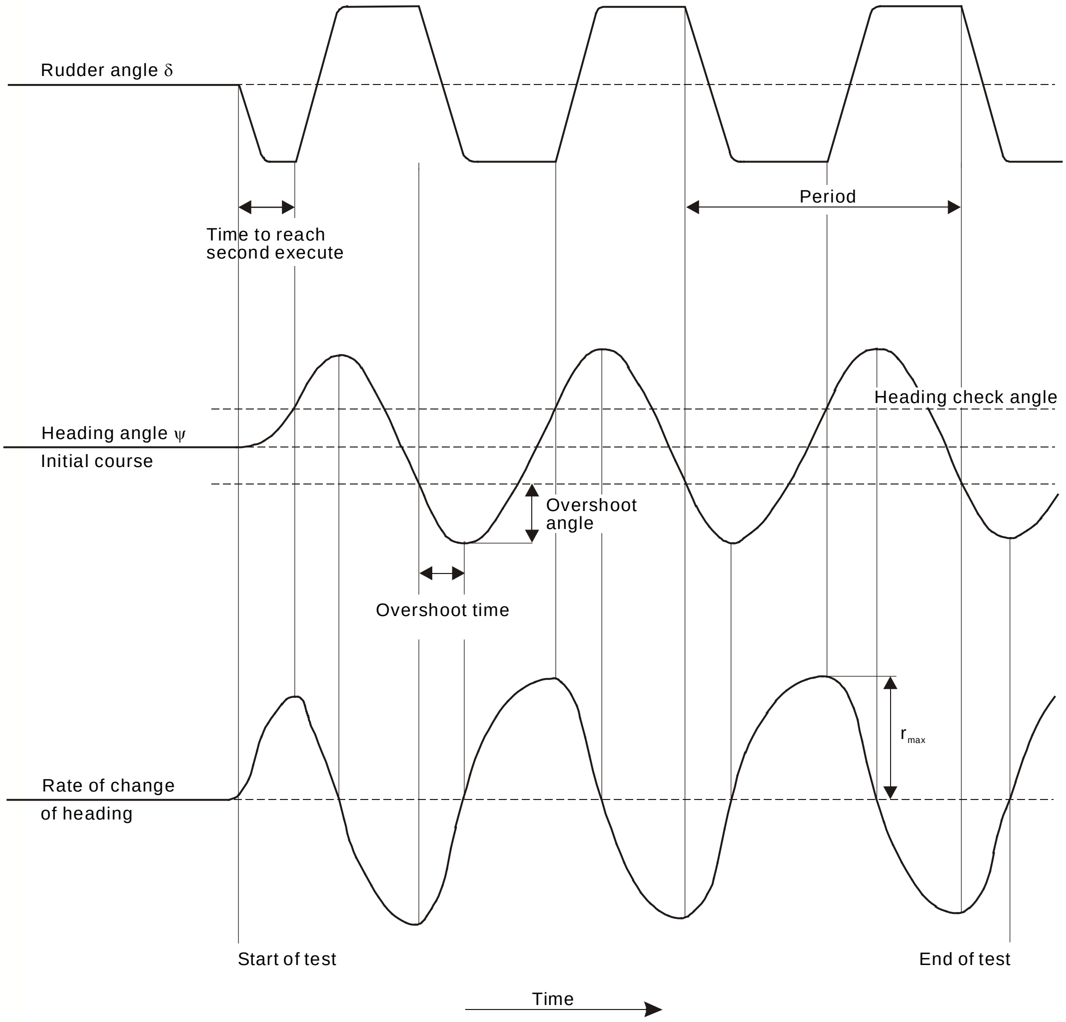
6.7 *Procedure for conducting zigzag simulations*

The vessel is initiated sailing at the desired approach velocity of the manoeuvre. The propulsion settings desired to propel the vessel at its approach velocity are determined by a pre-processor.

At the first time step, the rudder is laid to the desired angle to one side of the ship, say starboard, at a rate corresponding to the given rate of application. The ship model starts to turn and as soon as the heading has reached the pre-set heading check angle, the rudder is put over to the same angle to the other side (port). The ship model reverses its turn to the other side and as soon as the pre-set heading check angle to that side has been reached the rudder is put over to the same angle on the first side (starboard). The propeller revolutions or pitch settings are controlled and restricted as specified in the report. The process continues for several rudder executes after which the simulation terminates.
From the simulation results, the following parameters are derived:

DESIGNATION	UNIT	EXPLANATION
Approach speed (V_0)	kn	Approach speed of the manoeuvre
Rudder/yaw angle (□/□)	deg/deg	Pre-set rudder and yaw angle. The sign of the pre-set angles indicate the start of the manoeuvre. For example a -20/10 zigzag manoeuvre is started over starboard side. First rudder angle is 20 deg to starboard and the first yaw angle is 10 deg to starboard side.
Execute times	s	Time to reach second execute is the time elapsed from the moment the rudder is laid to the desired angle on one side (first execute) to the moment the rudder laid during for example the second or third execute
Reach	s	Time elapsed from the first execute to the moment the vessel returns to its initial course
Period	s	Period of a constant zigzag
Overshoot angles (d□)	deg	Yaw deviation from the moment the rudder is reversed to the moment the rate of change of heading is zero
Overshoot times	s	Time elapsed from the moment the rudder is reversed to the moment the rate of change of heading is zero
Initial turning ability	m	The distance travelled between the moment the rudder is laid (first execute) and the moment at which the pre-set heading deviation is realised. The initial turning ability is only derived from a 10/10 zigzag manoeuvre
Maximum roll angle (□)	deg	Maximum heel angle between the moment the rudder is laid to the desired angle on one side to the moment the rudder is reversed to the other side
Maximum drift angle (□)	deg	Maximum drift angle between the moment the rudder is laid to the desired angle on one side to the moment the rudder is reversed to the other side
Maximum rate of turn (r)	$deg \cdot s^{-1}$	Maximum rate of heading change between the moment the rudder is laid to the desired angle on one side to the moment the rudder is reversed to the other side

In the sketch below, the zigzag manoeuvre is shown graphically and the derived parameters are indicated.



6.8 Procedure for conducting combined turning circle / pull-out simulations

The vessel is initiated sailing at the desired approach velocity of the manoeuvre. The propulsion settings desired to propel the vessel at its approach velocity are determined by a pre-processor.

At the first time step, the rudder is laid to the desired angle to one side of the ship at a rate corresponding to the given rate of application of the steering unit. The ship model starts to turn and keeps turning with a constant steering angle. The propeller revolutions or pitch settings are controlled and restricted as specified in the report. When the ship model has completed at least one full circle the rudder is laid to zero rudder angle to start the pull-out manoeuvre. The simulation terminates when the vessel reaches a steady situation in the pull-out manoeuvre.

From the simulation results, the following parameters are derived:

DESIGNATION	UNIT	EXPLANATION
Approach speed (V_0)	kn	Approach speed of the manoeuvre
Rudder angle (□)	deg	The rudder angle with which the turning circle is sailed
Advance AD	m	Distance covered by the centre of gravity in the direction of the initial course when the ship has obtained 90 deg change of heading
Transfer TR	m	Distance covered by the centre of gravity in the direction perpendicular to the original course when the ship has obtained 90 deg change of heading
Tactical diameter TD	m	Tactical diameter, the distance covered by the centre of gravity in the direction perpendicular to the original course when the ship has obtained 180 deg change of heading
Turning diameter D_{stc}	m	Diameter of the turning circle in the steady turning condition, measured at the centre of gravity
T_{90}	s	Time required to obtain 90 deg change of heading with respect to the initial course from the moment the rudder is laid at t = 0 s
T_{180}	s	Time required to obtain 180 deg change of heading with respect to the initial course from the moment the rudder is laid at t = 0 s
T_{360}	s	Time required to obtain 360 deg change of heading with respect to the initial course from the moment the rudder is laid at t = 0 s
T_{stc}	s	Time required to sail a complete circle in the steady turning condition
$r_{execute}$	$deg \cdot s^{-1}$	Maximum rate of change of heading shortly after the rudder is laid
r_{stc}	$deg \cdot s^{-1}$	Rate of change of heading in the steady turn
$r_{residual}$	$deg \cdot s^{-1}$	Residual rate of turn during the pull-out
V_{stc}	kn	Speed in the steady turn
$\phi_{max\ inward}$	deg	Maximum heel angle inward shortly after the rudder is laid
$\phi_{max\ outward}$	deg	Maximum heel angle outward shortly after the rudder is laid
ϕ_{stc}	deg	Heel angle in the steady turn
Drift angle during turn β_{stc}	deg	Drift angle in the steady turn
Non-dimensional pivot point	m/L_{PP}	The pivot point in the steady turn relative to the centre-of-gravity, i.e. longitudinal point on the centre line with zero lateral velocity.

In the sketch below, the combined turning circle/pull-out calculation is shown graphically and the derived parameters are indicated.