Risk analysis of vessels exceeding horizontal boundaries in a channel

Final report

AVV Transport Research Centre
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Preface

The present M.Sc. thesis forms the completion of my education at the Delft University of Technology, Faculty of Civil Engineering and Geosciences, Department of Civil Engineering, Division Ports and Inland Waterways. The research has been performed by order of AVV Transport Research Centre, section Navigation and Waterways.

The study concerns the risk analysis of vessels exceeding horizontal boundaries in a channel. Subjects of study are, besides theoretical configurations, the approach channel to the harbour of IJmuiden (IJgeul).

For this research wind data observations were obtained from Directie Noordzee - Hydro - meteo advisering IJgeul (H.M.A.IJ.). The swell wave rose was attained from the Rijksinstituut voor Kust en Zee (RIKZ). Furthermore simulator input files (for current and bathymetry) were obtained from Alkyon. Many thanks go to them.

Special thanks go to Arno van der Hoek, who was my daily supervisor at AVV. I would also like to thank C. Davidse for her help in setting up the project, G. Riteco for his assistance in getting familiar with the simulator program NAVSIM, and B. Peters who assisted me with his seafaring experience during the real time simulation runs.

Furthermore I would like to thank the graduation committee for their supervision and personal help in bringing this project to a favourable end. The committee consists of:

- Prof. ir. H. Ligteringen (Chief Supervisor, DUT)
- Prof. drs. ir. J.K. Vrijling (Supervisor, DUT)
- Ir. R. Groenveld (Supervisor, DUT)
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Summary

In the preliminary stage of the entrance channel design one or more concepts of width, depth and alignment may be developed. Subsequently initial decisions (usually based on economic considerations) can be made to decide which alternative is the most likely to be chosen for more detailed design.

With reference to earlier research a need has risen for more fundamental research into the design of channels. Also in practice a need has risen in this field as the costs of entrance channels increase, due to the ever growing ship dimensions.

In this research the risk analysis of vessels exceeding horizontal boundaries is discussed. The analysis is limited to one failure mechanism, only the grounding of a ship on the shores of the channel due to a navigational error is considered.

The report is divided into two parts, first it presents the deterministic design method for the width of a channel developed by PIANC and a process is developed for the probabilistic design of the width. This probabilistic method takes, other then the deterministic one, the frequencies of the conditions into account. In the second part the probabilistic process is implemented in a case study about the IJgeul.

In order to be able to analyse the risk of exceeding the horizontal boundaries by a vessel one has to simulate the ship's behaviour under given natural conditions. Such a numerical ship manoeuvring equation is applied in ship simulator programs. Therefore in this research a ship simulator program will be used.

There are three different types of simulators:

- Real time simulator (full mission type)
- Real time simulator (bird's eye view)
- Fast time simulator

Also the human influence has to be incorporated in the risk analysis of the swept path of the ship. Therefore a real time simulator (bird's eye view) is used in this research for the navigation runs. The simulator program NAVSIM is on hand at AVV Transport Research Centre. The main advantage of the model is that the control of the ship can be handled 'real-time' by using the keyboard and mouse, as well as 'fast-time' in case of which the control of the ship is handled by an auto-pilot.

NAVSIM requires input variables as ship characteristics, bathymetry and natural conditions. The natural conditions comprising of wind-, current-, wave- and swell data have been generated from distribution functions by using random generators. Therefore joint probability density functions have been fitted through these data sets.

A 175,000 dwt bulk carrier has been chosen as the design ship. First a number of fast time test runs have been performed, the analysis of these runs permitted the evaluation of wind-, current- and swell conditions. Then it was possible to assess the limiting weather conditions for the channel navigation of the bulk carrier. A channel transit with a current velocity just before the harbour entrance greater than 0.6 m/sec was considered unsafe (horizontal tide). The minimum water level required for a safe transit is MSL +0.05 m (vertical tide).

A total of 1,000 weather conditions have been generated. Approximately 400 conditions complied to the horizontal and vertical tide criteria, as a result in 40% of the time a channel transit of the bulk carrier is possible. From the remaining 400 conditions (set I) the 51 most extreme ones (set I.2) were selected (see figure 1), and for these conditions fast time runs

were performed.

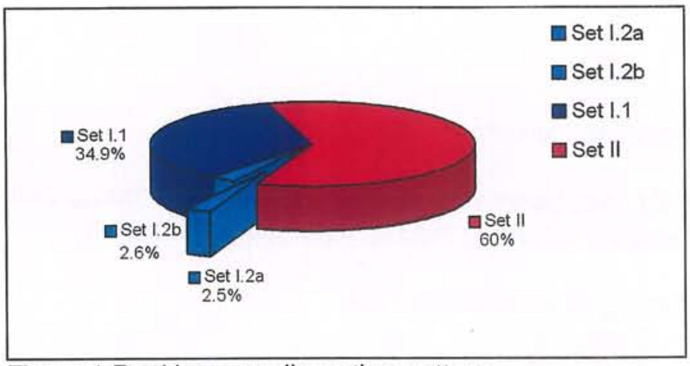

Figure 1 Partition overall weather pattern

The outcome of the 51 fast time runs was analysed using the following key performance factors:

- Rudder angle
- Drift angle
- Power burst
- Deviation from the desired track
- Speed at entrance harbour

The outcome of the performance factors was examined and a judgement was made, based on more detailed criteria for the performance factors, whether the channel navigation was feasible, critical or unacceptable. A total of 25 runs (set I.2a, see figure 1) were considered either feasible or critical.

Three conditions have been selected out of the feasible and critical runs. A total of 20 real time runs for each of these three conditions (number 26, 44 and 51 of the 51 extreme conditions) have been executed. The level of difficulty varies for these three conditions. From the output of the fast time simulations condition 44 was considered to be the most difficult, followed by condition 26, the least difficult weather circumstances for a navigation run is condition 51. This was confirmed by the real time runs.

The maximum excursions of the ship on port side as well as on starboard side were monitored during a run (see figure 2).

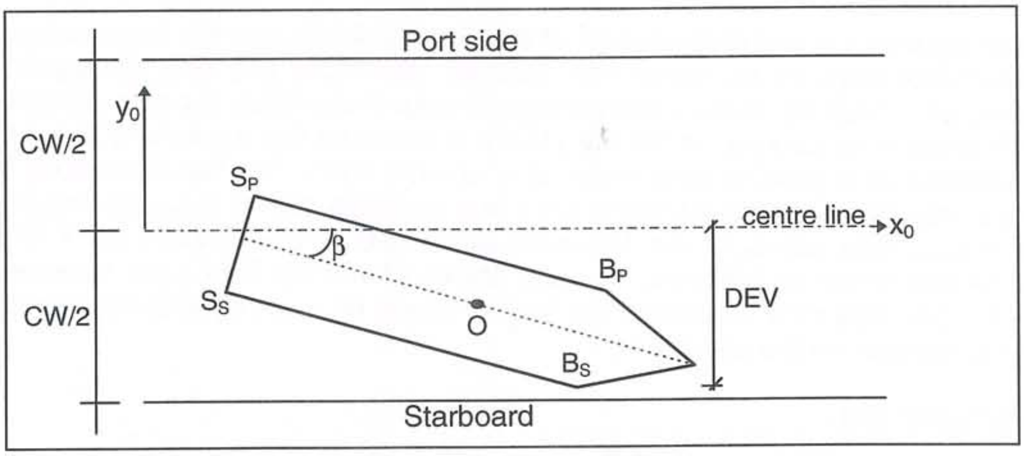

Figure 2 Definition sketch

where in this case $max_p = S_p$
$min_s = B_s$

Assuming symmetry around the centre line of the channel the maximal absolute excursion at every position is decisive for the required width.

$$\max_{\max} = MAX\left(\left|\max_p\right|, \left|\min_s\right|\right) \quad (1)$$

The half channel width should be larger than this value to avoid stranding.

The Generalised Extreme Value (GEV) p.d.f. has been fitted through the twenty $\max_{max}$ data points for each of the conditions. The parameter values of the GEV are given in table 1.

Table 1 Parameter values of the GEV for the $\max_{max}$ data points (set I.2a)

	Cond_26	Cond_44	Cond_51
γ	-0.173961	-0.103797	-0.556102
μ	56.7988	61.1713	61.1542
σ	3.50369	5.05844	2.37017
right endpoint	76.9394	109.905	65.4164

As can be concluded from table 1, all the GEV p.d.f. are of the Weibull type as $\gamma < 0$.

The fast time output data; $\max_p$, $\min_s$, swept path and $\max_{max}$ were compared to the real time data. It is striking that the absolute difference of the values of the swept path decrease as the difficulty of the runs increase. The mean value of the $\max_{max}$ value of the real time run divided by the one of the fast time run is on average 1.17.

The width of the IJgeul for a 175,000 dwt bulk carrier was determined using the deterministic design method developed by PIANC and also by applying the GEV p.d.f. for the three conditions. According to PIANC the total width of the channel should be 198 m.

A probabilistic design of the width for the extreme conditions is done in two ways, a width based on a safety criterion and an economic optimal width have been determined. Both the half channel widths for the different conditions are given in table 2.

Table 2 The half channel width (set I.2a)

	Cond_26	Cond_44	Cond_51
Safety criterion	73.75 m	93.68 m	65.40 m
Economic optimal width	69.45 m	80.37 m	65.40 m

In order to come up with a probabilistic design of the channel width also the frequencies of the natural conditions have to be taken into account. Therefore not only the extreme conditions should be monitored, instead the generated natural conditions have to represent the weather conditions for a long period of time. Here it is assumed that a total of 100 natural conditions is sufficient for a good representation of a weather chart. This has been done for two collections of natural conditions, condition set I and condition set I & 2 (overall weather pattern). The $\max_{max}$ data points of the fast time runs have been multiplied by 1.17 to incorporate some sort of human influence, see also above. Finally the GEV p.d.f. have been fitted through the two data sets. In table 3 the widths based on a safety criterion and the economic optimal channel widths are given.

Table 3 The half channel width

	Set I	Set I & II
Safety criterion	90.26 m	136.25 m
Economic optimal width	75.8 m	81.1 m

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1. Introduction

1.1 Background

1.1.1 General

In the preliminary stage of the entrance channel design one or more concepts of width, depth and alignment may be developed. Subsequently initial decisions (usually based on economic considerations) can be made to decide which alternative is the most likely to be chosen for more detailed design. The channel width of the chosen alternative should be designed to provide for the safe and efficient movement of the vessels expected to use the channel. The minimum channel width required depends on:

- the size and manoeuvrability of the vessels
- channel shape and alignment
- traffic congestion
- wind, waves and currents
- visibility
- quality and spacing of navigation aids
- one- or two way traffic

The width of the channel is measured at the bottom of the slope at the design depth. The present deterministic design method to determine the width has been developed by the PIANC Working Group [ref. 1].

The incorporation of human factors and marine risk are crucial elements. The aim of all design and operations is the safe and efficient movement of ship to and from a port and for this the safety (or risk) of the operation may have to be balanced against its cost in economic and commercial terms. A client may wish to have the safety and risk demonstrated in a tangible and measurable way so that they can be satisfied that the width (and alignment) of the channel is satisfactory.

The design tool which will assist in satisfying these requirements in Detailed design is the ship manoeuvring model. It is in the determination of channel width (and alignment) that it provides a powerful tool. A ship manoeuvring simulator is a mathematical model, installed on a computer, which reproduces as accurately as possible the manoeuvring behaviour of a ship.

1.1.2 Human factor

There are two main sub-divisions of the ship manoeuvring model:

- Fast time model
- Real time model

In a real time simulation model an experienced pilot operates the control actions on the helm, the engine and the tugs. In a fast time simulation model these actions are controlled by an auto-pilot.

1.1.3 Risk

A very crucial part of designing a harbour is the assessment of risks associated with the maritime traffic. A risk analysis of vessels operations is the direct link to overall economical evaluations of the port activities. It is of course, an extremely difficult task to provide absolute figures of risks in a port in the design stage. This is further elucidated in Chapter 3.

1.2 Problem definition

With reference to earlier research a need has risen for more fundamental research into the design of channels. Also in practice a need has risen in this field as the costs of entrance channels increase, due to the ever growing ship dimensions.

1.3 Objectives

In this research a probabilistic design method for the width of an entrance channel for the initial stage of the design process will be developed. This probabilistic method takes, other then the deterministic one, the frequencies of the conditions into account. Finally the method will be implemented in a case study about the IJgeul.

1.4 Starting points

- The method has to be applicable for all kinds of channels.
- The safety criteria developed by PIANC are applied in the model.

1.5 Assumptions

The assumptions made in the report are clarified in the various Chapters wherever these assumptions are vital to the subject.

1.6 Outline of the report

This report is the final report of the research, it is set out to provide the reader with a clear view of the project. The structure is as follows;

In Chapter 2, “Present design sequence for channels”, the design sequence for channels and the influence of the natural conditions on a vessel manoeuvring is described.

In Chapter 3, “Marine risk and safety of operation”, the overall marine risk and alleviation methods are elucidated.

In Chapter 4, “Probabilistic design of the width of a channel”, the overall method is given to design a channel width in the concept design stage.

In Chapter 5,"Site conditions IJmuiden", a start is made with the case-study about the IJgeul, in this Chapter the site conditions near the location are summarised.

In Chapter 6,"Simulator input", the input files for the NAVSIM simulator program are treated.

In Chapter 7,"Results of fast- and real time simulations", the output of the simulator is discussed and examples of output plots are given.

In Chapter 8,"Probabilistic analysis", the maximum excursion with respect to the centre line of the IJgeul is analysed and fitted with a GEV distribution.

In Chapter 9,"Channel width", the channel width for a 175,000 dwt bulk carrier is determined in several ways.

In Chapter 10,"Conclusions and recommendations", evaluation of the objectives and recommendations are made regarding further research to the topic.

2. Present design sequence for channels [ref. 1]

2.1 General

With the type and dimensions of the design ship chosen, the preliminary design of the channel may be undertaken. In this, one or more concepts of width, depth and alignment may be developed so that initial decisions can be made in order to choose the most likely candidate for the more detailed consideration.

The key parameters of alignment, width and depth are interlinked. However the linking is not strong and at the concept design stage, some aspects of width and alignment can, to a certain extent, be decoupled from those of depth. In channel width design the following aspects should be considered:

- Basic manoeuvrability
- Environmental factors:
    - Cross wind
    - Current
    - Waves
- Aids to navigation
- Type of cargo
- Passing distance
- Bank clearance
- Bends

In the following paragraphs these aspects are further elucidated.

2.1.1 Basic manoeuvrability

The dynamics of ships are such that, when under manual control they sweep a path, in the absence of all external perturbations from wind, waves, current, etc., which exceeds their breadth by a certain amount (figure 2-1). This is due to the speed of response of both the helmsman in interpreting the visual cues indicating position, and that of the ship in reacting to the rudder. Clearly the width of the swept path depends strongly on the inherent manoeuvrability of the ship and the ability of the helmsman.

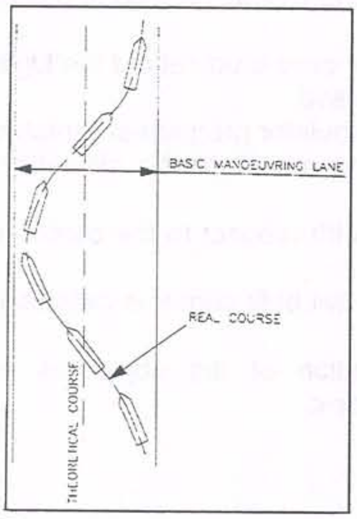


Figure 2-1 Width of manoeuvring lane

2.1.2 Environmental factors

Cross wind
Cross wind will affect the ship at all speeds, but will have the greatest effect at low ship speeds. It will cause the ship to drift sideways or to take up a drift angle, both of which increase the width required for manoeuvring. The ship will seldom be able to maintain a steady course at low speeds in a cross wind, the helmsman having to offer the ship up to the wind, resulting in a slightly oscillatory course (figure 2-2). Cross wind effects depend on:

- the windage of the vessel
- the depth/draught ratio
- the wind speed and direction relative to the ship

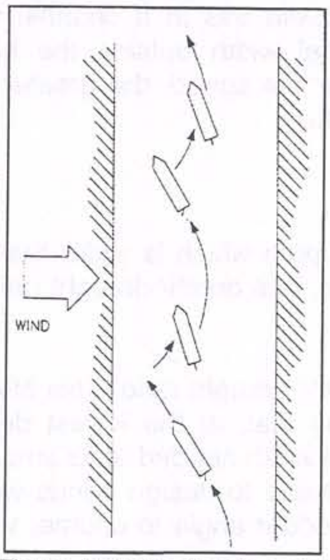


Figure 2-2 Handling in a strong wind

Current
Cross currents affect a ship's ability to maintain a course similar to wind, longitudinal currents affect its ability to manoeuvre and stop. The manoeuvrability of a ship reduces as its depth/ draught ratio approaches unity. As a result, its ability to cope with currents will also change as the water depth reduces.

Waves
Waves will naturally have an effect on channel depth, but if the wave fronts move across the channel they will also have an effect on the manoeuvring of the ship and therefore channel width. Waves can cause transient effects on yaw ('knocking' the ship's head off course) which can be corrected by the helmsman and they can also cause a mean drift in the direction of the wave.

2.1.3 Aids to navigation

The importance of aids to navigation lies in the cues they give to the helmsman. They will usually be visual although radar reflectors may be used. Electronic means are being developed in which a combination of DGPS and electronic charts may be used. A well marked channel will require less width than one that is poorly marked.

2.1.4 Type of cargo

If the cargo which is carried by the design ship is hazardous in nature, then an additional width allowance is required to reduce the risk of grounding. This because of the much greater impact of grounding of such ships on the surroundings.

2.1.5 Passing distance

If a two-way channel is proposed then some arrangement must be made to allow vessels to pass safely. A certain distance must ensure that ship-ship interaction is reduced to an acceptable minimum and it is usual to allow for a central 'strip', equal to a multiple of the beam of the larger passing ship, between the overall manoeuvring lanes of the passing vessel.

The width required for passing will also depend on the traffic density in the two lanes - the greater the density, the greater the width required.

2.1.6 Bank clearance

Bank suction can cause a ship to sheer uncontrollably. To avoid this in a channel with underwater banks it is necessary to allow additional channel width outside the basic manoeuvring lanes. This will depend on ship speed (the higher the speed, the greater the bank interaction), bank height and slope, and depth/ draught ratio.

2.1.7 Bends

In a bend the ship 'sideslips' as it turns and so sweeps out a path which is wider than its beam. This excess can vary from about 30% - 40% of the beam, at a depth/ draught ratio of 1.10, to 100% - 160% in deep water.

Therefore the way a ship turns depends very much on the depth/ draught ratio. This affects both the radius of turn and the width of swept track, showing that, at the lowest depth/ draught ratios the radius will be at its greatest and the additional width needed at its smallest (figure 2-3). In determining bend radius and width, it is inadvisable to design bends which require hard-over rudder angles. This would give no 'reserve' rudder angle to counter wind, wave or current and would therefore compromise safety.

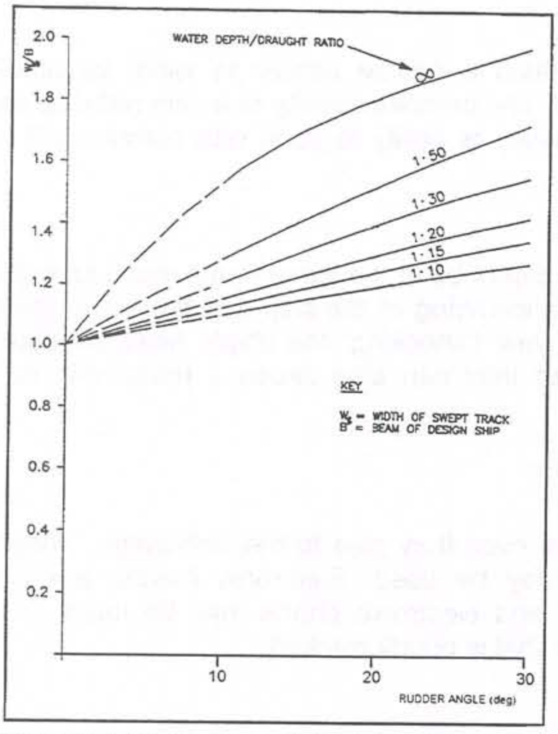


Figure 2-3 Width of swept track in a turn as a function of rudder angle and water depth

2.2 Concept design (Level I)

In this section a deterministic concept design method for the width of a channel is described. It is meant to be used in early design and trade-off studies. It represents good modern practice and channels designed to this method should result in an adequate level of navigational safety. Detailed design, which follows concept design, will address the particular features of a given site and is discussed in paragraph 2.3.

The bottom width w of the waterway (expressed as a multiple of the beam B of the design ship) (see also figure 2-4), is given for a one-way channel by:

$$w = w_{BM} + \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} \tag{1}$$

and for a two-way channel by:

$$w = 2 \cdot w_{BM} + 2 \cdot \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} + \sum w_p \tag{2}$$

where as shown in figure 2-4, w_{Br} and w_{Bg} are the bank clearances on the 'red' and 'green' sides of the channel, $\sum w_p$ is passing distance and the w_i are given in table 2-2. The basic manoeuvring width w_{BM}, as a multiple of the beam B of the design ship, is given in table 2-1.

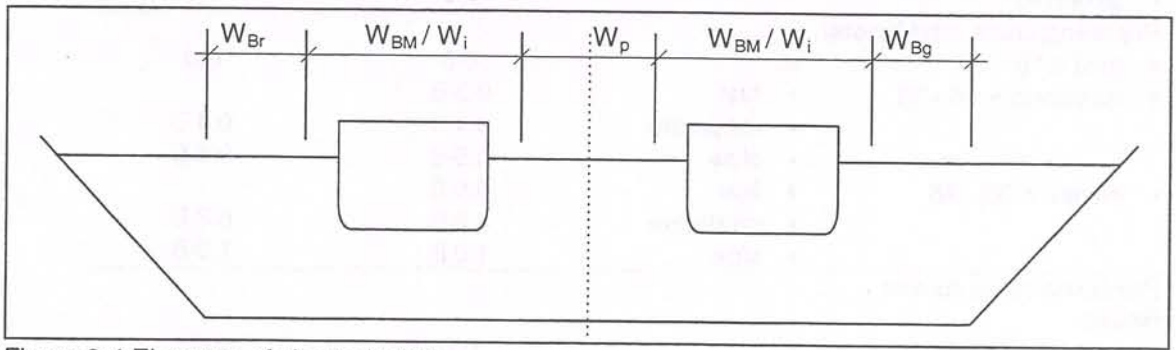


Figure 2-4 Elements of channel width

Table 2-1 Basic manoeuvring lane

Ship manoeuvrability	good	moderate	poor
Basic manoeuvring lane, w_{BM}	1.3·B	1.5·B	1.8·B

To the basic manoeuvring lane width w_{BM} additional widths are added (to allow for the effects of wind, current, etc.) which gives the total manoeuvring lane w. The additional widths are given in table 2-2, 2-3 and 2-4.

Table 2-2 Additional width for passing distance in two-way traffic

Width for passing distance, w_p	Outer channel exposed to open water	Inner channel protected water
Vessel speed [knots]		
• fast > 12	2.0·B	-
• moderate > 8 - 12	1.6·B	1.4·B
• slow 5 - 8	1.2·B	1.0·B
Encounter traffic density		
• light	0.0	0.0
• moderate	0.2·B	0.2·B
• heavy	0.5·B	0.4·B

Table 2-3 Additional width for bank clearance

Width for bank clearance (w_{Br} or w_{Bg})	Vessel speed	Outer channel exposed to open water	Inner channel protected water
Sloping channel edges and shoals:	• fast	0.7·B	-
	• moderate	0.5·B	0.5·B
	• slow	0.3·B	0.3·B
Steep and hard embankments, structures:	• fast	1.3·B	-
	• moderate	1.0·B	1.0·B
	• slow	0.5·B	0.5·B

Bend width and radius can be estimated from the ship turning data. A mean rudder angle for the bend should be chosen and the appropriate radius and width read off for a given depth/draught ratio (figure 2-3). Additional width for cross wind and current is preferably placed on the inside rather than on the outside of the bend.

Table 2-4 Additional widths for straight channel sections

Width w_i	Vessel speed	Outer channel exposed to open water	Inner channel protected water
Vessel speed [knots]			
• fast > 12		0.1·B	0.1·B
• moderate > 8 - 12		0.0	0.0
• slow 5 -8		0.0	0.0
Prevailing cross wind [knots]			
• mild ≤ 15	all	0.0	0.0
• moderate > 15 - 33	• fast	0.3·B	-
	• moderate	0.4·B	0.4·B
	• slow	0.5·B	0.5·B
• severe > 33 - 48	• fast	0.6·B	-
	• moderate	0.8·B	0.8·B
	• slow	1.0·B	1.0·B
Prevailing cross current [knots]			
• negligible < 0.2	all	0.0	0.0
• low > 0.2 - 0.5	• fast	0.1·B	-
	• moderate	0.2·B	0.1·B
	• slow	0.3·B	0.2·B
• moderate > 0.5 - 1.5	• fast	0.5·B	-
	• moderate	0.7·B	0.5·B
	• slow	1.0·B	0.8·B
• strong > 1.5 - 2.0	• fast	0.7·B	-
	• moderate	1.0·B	-
	• slow	1.3·B	-
Prevailing longitudinal current [knots]			
• low ≤ 1.5	all	0.0	0.0
• moderate > 1.5 - 3	• fast	0.0	-
	• moderate	0.1·B	0.1·B
	• slow	0.2·B	0.2·B
• strong > 3	• fast	0.1·B	-
	• moderate	0.2·B	0.2·B
	• slow	0.4·B	0.4·B

Continuation table 2-4

Width w_i	Vessel speed	Outer channel exposed to open water	Inner channel protected water
Significant wave height H_s and length λ (m)			
• $H_s \leq 1$ and $\lambda \leq L$	all	0.0	0.0
• $1 < H_s < 3$ and $\lambda = L$	• fast	$\approx 2.0 \cdot B$	
	• moderate	$\approx 1.0 \cdot B$	
	• slow	$\approx 0.5 \cdot B$	
• $H_s > 1$ and $\lambda > L$	• fast	$\approx 3.0 \cdot B$	
	• moderate	$\approx 2.2 \cdot B$	
	• slow	$\approx 1.5 \cdot B$	
Aids to navigation			
• excellent with shore traffic control		0.0	0.0
• good		$0.1 \cdot B$	$0.1 \cdot B$
• moderate with infrequent poor visibility		$0.2 \cdot B$	$0.2 \cdot B$
• moderate with poor visibility		$\geq 0.5 \cdot B$	$\geq 0.5 \cdot B$
Bottom surface			
• if depth $\geq 1.5 \cdot T$		0.0	0.0
• if depth $< 1.5 \cdot T$ then			
• smooth and soft		$0.1 \cdot B$	$0.1 \cdot B$
• smooth or sloping and hard		$0.1 \cdot B$	$0.1 \cdot B$
• rough and hard		$0.2 \cdot B$	$0.2 \cdot B$
Depth of waterway			
• $\geq 1.5 \cdot T$		0.0	$\geq 1.5 \cdot T$
• $1.5 \cdot T$ - $1.25 \cdot T$		$0.1 \cdot B$	0.0
• $< 1.25 \cdot T$		$0.2 \cdot B$	$<1.5 \cdot T$-$1.15 \cdot T$
			$0.2 \cdot B$
			$< 1.15 \cdot T$
			$0.4 \cdot B$
Cargo hazard level			
• low		0.0	0.0
• medium		$\sim 0.5 \cdot B$	$\sim 0.4 \cdot B$
• high		$\sim 1.0 \cdot B$	$\sim 0.8 \cdot B$

2.3 Detailed design

If a fairway safety study is to result in reliable quantitative conclusions, such as a well-balanced selection between different fairway layouts, one of the following approaches could be considered.

In some situations, full scale experiments are performed, which are, of course, superior to any other type of experiments when it comes to representing reality. It may be evident that utilising real vessels, even if the trials are not concluded with running a loaded super-tanker aground, is generally very expensive.

Furthermore navigation and manoeuvring simulators are used as advanced means for the analysis of new situations. The aim of the system is to reproduce the behaviour of a specific ship during a manoeuvre when subject to the action of the wind, waves and current, and assisted by tugs. The simulator includes a mathematical model which calculates the ship's track and motion. There are three different types of simulators;

- Real time simulator (full mission type)
- Real time simulator (bird's eye view)
- Fast time simulator

Real time simulator (full mission type)
It is the pilot or captain who decides and executes the actions on the helm, the engine and the tugs so that the ship follows a safe trajectory. For this aim, the simulator includes a bridge mock-up with the main instruments (rudder bar, engine telegraph, indicators, etc.) and visual information on the external surroundings is received via a radar screen and a view of the manoeuvring zone. Furthermore, the previous operations occur in real time, so that the perception, information analysis, decision-making and execution cycle are carried out in similar conditions to the real situation.

Real time simulator (bird's eye view)
This simulator does not have a bridge mock-up, instead the vessel can be handled by the keyboard and the mouse. Visual information, a bird's eye view of the channel, is received on a monitor. The instrument panel is projected on a second monitor, it contains regulators for engine and rudder control. These regulators are controlled by a pilot or captain.

Fast time simulator
These types of simulators have an auto-pilot instead of a pilot or captain. The auto-pilot responds to deviations from the desired track and course angle. In the case of curved tracks and changes in the current pattern, the auto-pilot will anticipate on these changes, while taking into account a user defined anticipation distance. Furthermore the previous operations can occur in fast time, as no pilot or captain is handling the ship, thus saving time.

In some cases a pilot control model is used instead of the auto-pilot. This model approximates the behaviour of the pilot or captain on board of a ship. Using this model one can analyse the resulting statistics of the runs.

Papenhuijzen [ref. 11] developed two human operator models of the navigator; the control theoretic navigator model and the fuzzy set navigator model. The fuzzy set navigator model schematises the human influence best as can be seen in Appendix I.

3. Marine risk and safety of operation [ref. 1]

3.1 Introduction to marine risk

3.1.1 Marine risk

The concept of risk in the marine world is linked to the frequency of accidents and their consequence. With regard to the safety of life at sea for example, the consequence of an accident will be measured in the number of casualties and the risk to life will be given by:

$$Risk = f_a \cdot N_c \tag{3}$$

where f_a is the frequency of an accident
N_c is the number of casualties

In a port and its approaches the consequence of an accident may not be loss of life, but serious damage to the environment or loss of revenue to the port. The former is of increasing concern and the potential environmental impact of any port development is nowadays carefully scrutinised. The latter consequence may arise from the port approach channel being blocked as a result of an accident, thereby preventing some or all of the marine traffic which uses the port from so doing.

In such cases the consequence of the accident will not be measured by the number of human lives lost, but by other measures of both damage to the environment and loss of revenue. The equation for marine risk then becomes:

$$Risk = f_a \cdot M_c \tag{4}$$

where M_c is some measure of the consequence of the accident

When life at sea is at risk, N_c is minimised by ship design, on board life-saving equipment and the search and rescue (SAR) capabilities to hand. When the environment is at risk, the consequence may be minimised by careful ship design (e.g. double hull tankers) and provision of rapid reaction containment facilities.

When the consequence of an accident could result in blocking the approach channel, the width of the channel must be considered carefully and consideration must be given to standby tugs, escort tugs, rules of operation and the like.

While the consequence of an accident may be susceptible to the design of ship and its operation, the frequency f_a in equations (3) and (4) is also related in part to ship design and in part to its operation. In this regard a badly designed ship may well be more prone to accidents, as well as one that is poorly operated. In approach channel design, it is usual to concentrate on the operational components of f_a and to ensure that these do not give rise to unacceptably high values of f_a. It is therefore assumed that little can be done to change the relation between f_a and ship design as most ports have to accept ships (and their designs) from many areas of the world. Occasionally it is possible to design a ship specifically for dedicated operation in a given approach channel, and in such a case, some control over f_a can be envisaged by this means.

The parameter f_a itself is specified generally as 'accident rate' or 'incident rate' and may be expressed as a probability such as:

accident rate = x in 10^6 encounters
or x in 10^3 shipping movements

where x is the number of accidents

Accidents to ships are classified under a number of technical headings. The ones of most interest to the port approach channel designer are:

- collision; a collision occurs when two vessels under way, drifting or on tow come in contact.
- grounding; a grounding occurs when a vessel under way comes into contact with the bed of the waterway, berth or bank of a fairway, canal or river.
- stranding; the consequence of a grounding in which the ship is left high and dry.
- impact; impact occurs when a vessel under way, or drifting, hits an immovable object such as a jetty.
- striking; striking occurs when a ship underway hits a drifting floating object such as a ship at anchor, floating dock or buoy.

All of these have precise definitions and may be regarded as events associated with navigation or ship handling and, as such, will be influenced by the design of the channel. This research is limited to one failure mechanism, only the grounding of a ship on the banks of the channel due to a navigational error is considered here.

It is usual in matters of approach channel design to try to reduce f_a in equations (3) and (4). There are exceptions of course when the consequence of any accident are so potentially damaging that they must be given equal weight in the channel design process. However, efforts will generally be concentrated on keeping the potential accident rate f_a to an acceptable level.

3.1.2 Estimation of marine risk

The accident rate (or probability) is determined for each of the accident categories and any others that are relevant. The overall marine risk is then the sum of these individual, independent risks:

$$r_o = r_c + r_g + r_s + r_i + r_{st} \qquad (5)$$

where r_o is the overall marine risk
r_c is the risk of collision
r_g is the risk of grounding
r_s is the risk of stranding
r_i is the risk of impact
r_{st} is the risk of striking

These figures are quoted on a consistent frequency or probability basis which may be related to time, e.g. incidents per annum or to the total number of movements or transits, e.g. incidents per 1,000 transits or similar convenient measures.

Risk, or changes in risk due to the design developments, can be assessed by computer models. In this case, event-driven simulations can estimate the number of encounters between ships in a given traffic and these may be related to collision risk, one of the elements in equation (4). Such computer models or Traffic Planners can be used in a busy port, provided proper databases are available to develop and calibrate the model.

There are one or two semi-empirical expressions which give incident frequencies directly. From experience in a number of port approaches, the following relationship was developed:

$$f_g = K \cdot \frac{L_c}{w} \quad \text{per transit [ref. 1]} \qquad (6)$$

where K is a constant, evaluated at 10^{-5} per transit
L_c is channel length
w is channel width

This expression is a statement of the probability that a grounding is more likely in a long channel and less likely in a wide one.

A similar expression may be developed for the striking frequency f_{st} where:

$$f_{st} = K \cdot R \cdot \frac{L_f}{w_f} \quad \text{per transit [ref. 1]} \qquad (7)$$

where K is a constant
R is the probability that last-minute recovery action will be unsuccessful
L_f is the length of the floating object profile along the channel
w_f is the distance of the floating object from the normal average track of the channel (i.e. cross track error)

3.1.3 Risk alleviation methods

Once the marine risk has been estimated for the new situation (i.e. for the new channel operation) it must be compared with either the existing situation or agreed international standards. A judgement must then be made as to whether the new situation is acceptable or not. If it is not, means of alleviating the risk must be found. Apart from re-designing the channel, the following are at the disposal of the channel operator:

- Vessel Traffic Service (VTS)
- Operating Limits
- Rules of Operation
- Aids to Navigation
- Traffic Separation Schemes

These are now discussed further.

3.2 Alleviation of marine risk

3.2.1 Vessel Traffic Service (VTS)

A VTS is an advisory service for mariners. It provides advice and information to mariners on ships passing through the system. Surveillance of traffic is carried out by the VTS centre, with information passed from ships to the centre at prescribed 'reporting in' points. Confirmation of ship names may be carried out by aerial surveillance if it is not possible to identify a ship by other means.

Such systems are used in ports and international waterways, and while the overall control of the ship rests at all times with her master (aided by the pilot) the VTS centre may require the ship to adhere to certain requirements for the safe operation of the port. Examples are:

- Adhere to the port speed limit
- Remain alongside at anchor
- Do not proceed beyond a given point until clearance is given

Radar surveillance will be used with such a system and arriving ships may be 'tagged' with an identifier which remains with their radar target for the duration of their stay in the port. Often a digital log of all tagged ship movements is kept, samples being taken every few minutes, so that a hard-copy is available of all shipping activities within the waterway and the port.

3.2.2 Operating limits

Operational limits are a powerful means of mitigating marine risk. They will provide the basis for tug operations, down-time, emergency scenarios and berth operation and therefore have a very powerful influence on the operation of a port.

Many limits may already be in place in an existing port, having evolved as a result of operational experience over a number of years. These should be understood and respected by the designer who may then wish to add to or modify them as a result of a new port development. Initial changes can be made at the design stage as a result of a new port development. Initial changes can be made at the design stage as a result of the use of ship simulation, combined with discussions with local mariners. As operational experience with the new port development builds, the limits can be tightened or replaced as appropriate.

3.2.3 Rules of operation

Operational limits lead naturally to rules of operation which are their ultimate manifestation in the operation of the port. They determine, for example, when it is safe for certain classes of ship to navigate certain areas, what to do in emergency situations and so on. They may be supplemented by guides to masters provided, for example, by terminal operators in which much practical information on terminal operations and safety requirements is often supplemented by local rules of operation.

Rules of operation may be used not only to improve safety, but also to reduce channel cost. For example, restricting operations to high water means that a more shallow channel can be dredged with resultant savings in capital and maintenance dredging costs. Against this advantage must be set the disadvantage of delays to incoming or out-going ships which in themselves will have an economic penalty. The commercial cost of the accumulated delays for deep-draughted ships may justify an increase in channel depth if the period for which they are unable to navigate the channel (or 'downtime') is excessive.

Periods of downtime may result from the effects of currents, wind, waves and poor visibility. If downtime is scheduled and enforced for some significant period of time, it is possible to reduce the channel dimensions without jeopardising the safety.

The introduction of navigation windows and downtime, enforced by the channel authority in order to avoid unsafe situations, will to some extent hamper the navigation through the channel with the following potential impact. The ship waiting time, before a ship will be able to negotiate the channel, will increase and the accumulated time period of all ships affected by the restrictions, will represent an economic loss each year.

The viability of imposing the restrictions mentioned in this section should be checked and assessed on general transportation economic grounds.

3.2.4 Aids to navigation

Aids to navigation are a vital element in the alleviation of marine risk. Their type, size and positioning must be determined as an essential part of marine-side design. Practising mariners (usually the local pilots) should be consulted for their views on the proposed aids and their placement with, if possible, the use of real or fast time simulation for their assessment.

Channel markers buoys should be conspicuous with light characteristics or radar reflectors that allow them to be easily identified against a background of other lights, or in bad visibility.

Gated pairs of buoys are preferred for marking straight channel legs, with spacing adequate for the probable visibility conditions. In the critical area of a channel, such a longitudinal spacing is about a nautical mile as a maximum, as this is the greatest spacing for which a pilot would be happy to maintain control based on his visual perception of the channel as marked by buoys.

Conventional chain-moored buoys or piled beacons may be considered as channel markers and usually the choice is based on cost and channel usage. Piled beacons have the advantage that they do not move, while moored buoys will move in a tidal stream to the scope of their moorings. Should the moorings break, they could drift off station.

Beacons or buoys should be placed as close to the dredged channel edges as is practicable, and must all conform to IALA requirements.

Leading marks (or 'ranges') are an alternative method of marking a straight channel leg. They are expensive due to the structures required to support them at the correct height. They are sometimes difficult to use if the ship must adopt a large drift angle, or if they are only visible astern rather than ahead. The correct separation and height of leading lights may be determined from the IALA recommendations.

Electronic position fixing systems are provided in some areas. Many ships are now fitted with satellite-based navigation systems (such as DGPS) which will indicate their position very accurately. Combined with electronics charts (ECS, ECDIS) it will be possible, in principle, to determine very accurately where a ship is in relation to a marked channel. Electronic bearing markers (e.g. RACONS) are provided as fixed reference marks from which to take bearings.

3.2.5 Traffic separation schemes

Traffic separation schemes (TSS) alleviate risk by segregating traffic into lanes of ships all moving in the same direction with a traffic separation zone between the lanes. There may also be inshore traffic zones for small craft who do not use the main traffic lanes. Crossing the TSS is done under a strict set of rules and often at known crossing points.

3.3 Pilotage considerations

3.3.1 General

Handling ships in the waters of a harbour will be the responsibility of a number of groups of mariners. These include ferry masters, tug masters and other small craft operators.

The majority of ocean-going ships however will be handled by qualified pilots who combine ship-handling skills with local knowledge of special conditions in the pilotage area. They will have technical knowledge and will also be well versed in the regulatory and environmental requirements of the port area.

This combination of abilities is a valuable resource for the designer of port waterways. The pilot's value as a member of the design team and his advisory role for ship-handling matters is apparent in the discussions given above on the use of simulation. However, there are other aspects relating to pilot operations which may affect waterway design and these are now considered.

3.3.2 Pilot variability

Pilots are human and while all should attain a high degree of competence, some will be better than others. The ability of those that take part in simulator exercises may well be biased toward the better end of the spectrum either because they are the most experienced and senior pilots, or because they have themselves taken a technical interest in port design and simulators in the past.

While such pilots will be of great benefit to the design team, it must be recognised that they may represent the best available. The question of how much allowance should be made for the variability in pilot capabilities is not an easy one to answer, but some allowance must nevertheless be made.

3.3.3 Pilot boarding areas

A pilot must board the ship at a suitable location. These boarding areas must be properly located and this may concern the waterway designer. At such locations ships may slow down and account may need to be taken of this in the local channel design.

The boarding area should ideally be in waters not subject to severe seas or swells, which would make pilot boat operation difficult or impossible. If long transits are needed then alternatives to the pilot boat such as helicopter transfers may need to be considered. In such cases, a sea area where safe helicopter transfers can take place may need to be considered by the designer.

3.3.4 Anchoring areas and lay-by berths

A pilot may decide that berthing the ship, or further transit along the channel cannot proceed. This may be because, in his view weather conditions have deteriorated past the limits for safe operation, the tidal 'window' he had is now closed, an emergency has arisen ahead of his ship or one of a number of other reasons.

If the reason for this is likely to disappear in the short term, he may choose to 'stop and hold' his ship in the channel. If not he will have to anchor or make fast to a lay-by berth. The latter is more likely to occur in river or estuary passages with large tidal ranges and strong currents, but both measures should be allowed for in the design.

Suitable anchorage areas and/or lay-by berths should be provided along the waterway. These will be positioned in relation to:

- berth location
- transit speeds and times
- tidal characteristics
- currents
- weather data

In addition, anchorage location will have to take into account:

- sea bed composition
- sea room for a ship to swing at anchor

3.3.5 Safety aspects

The pilot's primary aim, having regard to the limitations of the channel and the vulnerability of port installations, is to ensure the optimum expedition consistent with maximum safety of the ship in his charge. By his training and experience he will know what is safe and is therefore a valuable source of advice in simulator studies. In some cases he may be the only means whereby safety can be assessed, if no other measures or safety criteria are available.

4. Probabilistic design of the width of a channel

4.1 Introduction

In Chapter 3 the overall marine risk is described. This research is limited to one failure mechanism of the approach channel (see paragraph 3.1.1). Only the grounding of a ship on the banks of the channel due to a navigational error is considered here. A grounding occurs when a ship under way comes into contact with the bed of the waterway, berth or bank of a fairway, canal or river.

The probability of grounding is assumed to be equal to the probability that the ship exceeds the horizontal boundaries of the channel. The vertical grounding probability is not taken into account.

4.2 History

In this research two probabilistic design methods for the width of a channel have been analysed.

- PRODIM, this computer program was developed for AVV by ORTEC consultants (see Appendix II)
- Ennore, this method was developed by Prof. Drs. J.K. Vrijling for the harbour of Ennore, India (see Appendix II)

PRODIM is not a ship simulator program, therefore no pilot or captain is needed to execute ship runs. As input for the program the traffic intensity in the channel, the vessel characteristics (width, length, speed, etc.) and the wind circumstances are required. It assumes a relation between the drift angle and the wind velocity perpendicular to the vessel. The program generates traffic situations and calculates the required width and their probability of occurrence. Subsequently with a given safety criterion one obtains a belonging width of the channel. PRODIM is a very limited probabilistic method, it is only valid for inland waterways, the variables are independent, it does not have an automatic pilot and the human factor is not simulated.

The Ennore method tries to simplify the ship's maximum excursion of the centre line to one equation; $DEV = |NE + PE| - \left|\frac{L}{2} \cdot \sin\beta\right| - \frac{B}{2}$ (8)

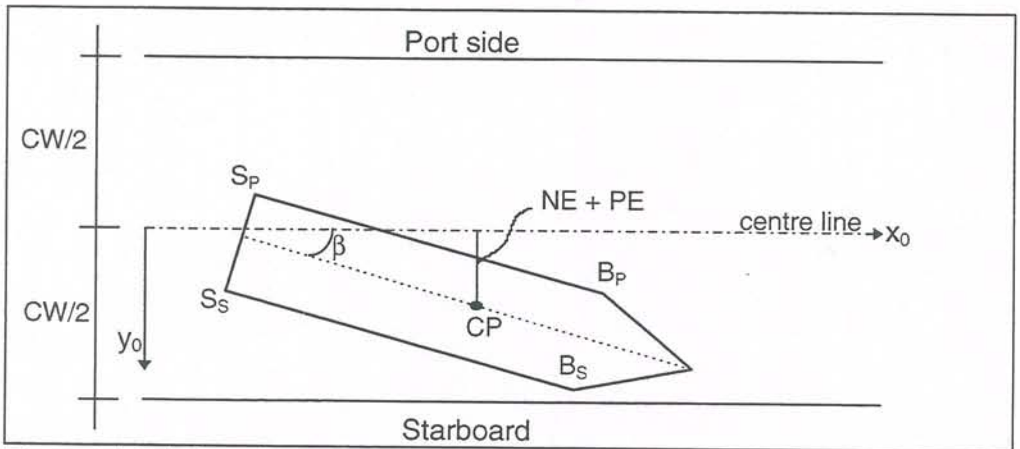


Figure 4-1 Ship in a channel

where DEV = deviation of the ship to the centre-line of the channel
NE = navigation error
PE = position error
β = drift angle
B = width vessel
L = length vessel

The variables in this formula (NE, PE and β) are assumed to be normally distributed. Subsequently the probability density function of the width of the channel can be determined. A disadvantage of the method is that it does not take the variable natural conditions into account, although this can be done by expanding the equation. After consultation it appeared to be difficult to develop a static equation which simulates the swept path under given natural conditions. This can be solved by drawing up a numerical ship manoeuvring equation. These equations are already being applied in ship simulator programs.

For the foregoing reasons both methods will not be elaborated any further. In the following paragraph the method is set out which will be used further on.

4.3 Probabilistic design

4.3.1 General

As stated in paragraph 4.2 it is important to be able to predict the ship's behaviour under given natural conditions. Therefore the choice has been made to use a ship simulator program. Secondly the influence of the helmsman should also be incorporated in the runs. The three options now are (see paragraph 2.3):

- Real time simulator (full mission type)
- Real time simulator (bird's eye view)
- Fast time simulator with fuzzy set navigator model

The fast time simulator with the navigator model is by far the most attractive option. The main advantage is the model's high calculation speed, as a result a run takes a considerably less amount of time in comparison with a real time run. Furthermore no experienced pilot or captain is required to perform the runs. In spite of these advantages this model can not be implemented in this research as it is not operational at the moment.

The execution of runs with the full mission real time simulator is very expensive, for this reason this option has not been chosen. As a result the runs will be executed with a real time simulator with a bird's eye view. Such a simulator is present at AVV Transport Research Centre. Further on this simulator program will be referred to as NAVSIM (see Appendix III).

4.3.2 Input data

The simulator program needs input variables as ship characteristics, bathymetry and natural conditions. The variable natural conditions as wind, wave and current data will be drawn from distribution functions by using random generators. Therefore first joint probability density functions (figure 4-2) have to be fitted through the data sets;

- Wind; velocity and direction
- Current; velocity and direction
- Waves; height and direction

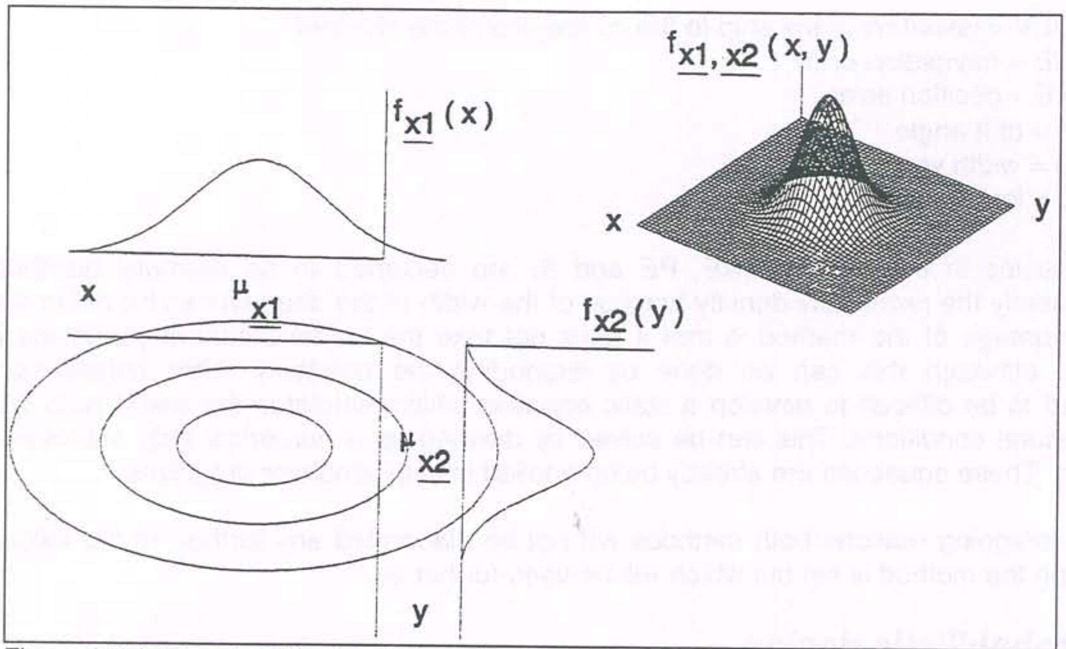


Figure 4-2 Joint probability density function

The assumption has been made that the data are given in the form of a wave-, wind- and current rose. These natural conditions are mutually dependent, this will be dealt with in Chapter 5. In this paragraph the basic concept how to generate natural conditions from density functions is treated. For this purpose the software program Matlab is used. As an example the program which generates wave direction and wave height data (WAVE), will hereafter be treated.

WAVE first generates an angle of direction of wave propagation, subsequently a wave height is generated using the wave height distribution function belonging to the wave direction class. In order to generate these data the inverse cumulative distribution function has been used.

If X is a scalar random variable with a continuous cumulative distribution function (CDF) P_X, then the random variable

$$U = P_X(X) \qquad (9)$$

has a U(0,1) distribution. This fact provides a very simple relationship with a uniform random variable U and a random variable X with distribution function P:

$$X = P_X^{-1}(U) \qquad (10)$$

In figure 4-3 it is shown how to convert the random variable into a value X.

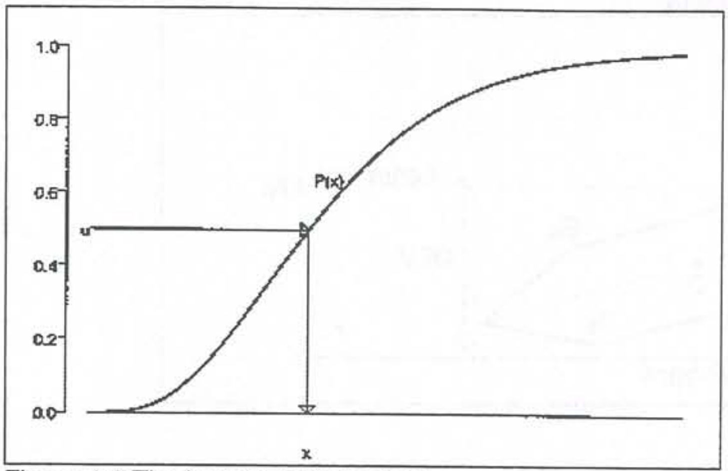


Figure 4-3 The inverse CDF method

By using the interpolation technique, the CDF method can also be applied if the distribution function is not continuous. The Programme Structure Diagram (PSD) of WAVE is given in figure 4-4.

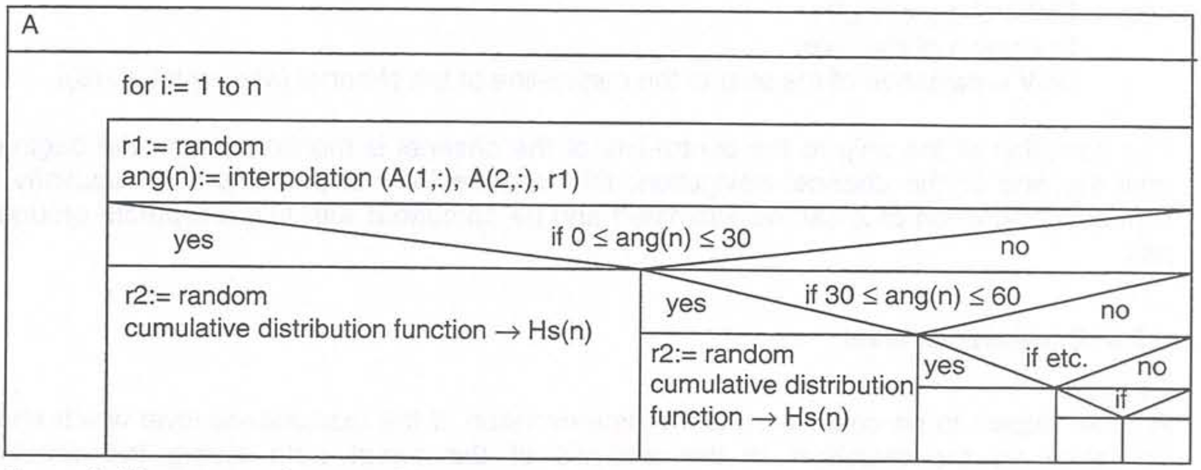


Figure 4-4 Programme Structure Diagram of WAVE

where A is a 2×13 matrix containing the wave angles (0, 30, 60, etc.) and the numerical cumulative distribution function
r1 and r2 are random values with a (0,1) distribution
Ang(n) is a n×1 matrix containing the generated wave angles
Hs(n) is a n×1 matrix containing the generated wave heights

4.3.3 Output data

As already stated in paragraph 4.1, the deviation of the ship to the centre-line of the channel is further analysed. Figure 4-5 gives a definition sketch of the channel navigation.

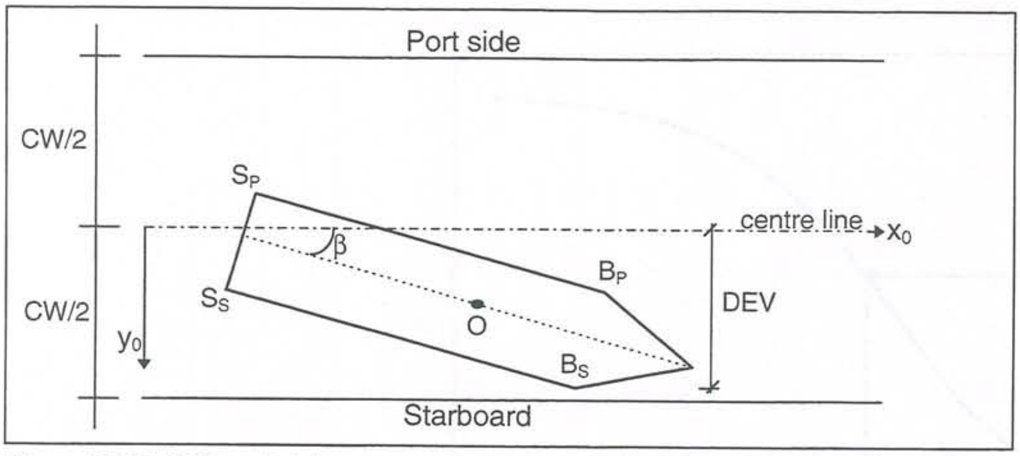


Figure 4-5 Definition sketch

As a result a reliability function of the crossing of the channel border by the vessel can be drawn up.

$$Z = \frac{CW}{2} - DEV \tag{11}$$

where CW = channel width
O = origin of the ship
DEV = deviation of the ship to the centre-line of the channel (see equation (8))

The deviation of the ship to the centre-line of the channel is monitored from the beginning until the end of the channel navigation, this is done for multiple runs. Subsequently the distribution function of Z can be estimated and be compared with the acceptable grounding risk.

4.3.4 Exceedance level

General

Another aspect to be considered is the determination of the exceedance level which should be taken as the threshold in the analysis of the swept path during the simulated manoeuvres. This process will normally begin with the establishment of an admissible risk in the fairway.

To find the acceptable probability of stranding for one stretch of channel and one vessel, the number of independent stretches and the number of vessels per year have to be taken into account. The length of an interdependent stretch relates to a half wavelength of the ships track in the channel, which is estimated at 4-5 ship lengths.

$$p_{acc|ship,stretch} = \frac{p_{str}}{N_{year} \cdot N_{ships} \cdot N_{stretch}} \tag{12}$$

where $p_{acc|ship,\ stretch}$ = the acceptable probability of stranding per ship per stretch
p_{str} = the acceptable probability of stranding in the considered planning period
N_{year} = the service time envisaged for the fairway in years
N_{ships} = the number of ships entering the port every year
$N_{stretch}$ = the number of independent stretches

Safety criteria

The rational measurement of safety and the setting of standards against which a channel design can be judged are problems which as yet do not have universal solutions. The following criteria have been established in two different studies and are recommended by PIANC to use as limiting probabilities in channel design. The choice of the norm level is based on a calculation of the risk levels for a large number of locations.

1. Limiting probability of exceedance of lane width for the planning period is 0.5 [ref. 16]
2. Limiting probability of exceedance of passing distance with two-way traffic for the planning period is 0.2 [ref. 16]
3. The probability that no accident will occur during 10 years of operation for a 10 km long fairway is 0.6 [ref. 17]

The limiting probability of exceedance of lane width or passing distance is valid for the exceedance of the port side- and starboard bank during the lifetime of the channel for all transits. The acceptable probability of stranding per ship per stretch ($p_{acc|ship,\ stretch}$) is for criterion (1) smaller than for criterion (3). This makes sense as criterion (1) only comprises the risk of grounding of a vessel due to exceedance of lane width where criteria (3) comprises of the overall marine risk.

Economic criteria

A rational approach schematises the choice for an economic decision problem where the risk of a stranding (probability × consequence) is expressed in monetary terms. The reduction of the risk is then equated with the costs of widening the channel. This approach results in comparatively narrow channels if widening carries a high cost and vice versa. From a standpoint of standardisation this may seem odd, but it is economically rational.

The present value of the risk of stranding is;

$$M_{risk} = \frac{P_b \cdot S}{r'} \tag{13}$$

where P_b = probability of stranding
S = consequence in terms of money
r' = real interest rate

The construction costs are;

$$C_c = I_0 + I' \cdot CW \tag{14}$$

where I_0 = initial costs; design, research, etc.
I' = variable costs (dredging costs for widening the channel one meter)
CW = channel width

The total costs comprise of the construction costs and the present value of the risk of stranding;

$$C_{tot} = I_0 + I' \cdot CW + \frac{P_b \cdot S}{r'} \tag{15}$$

When the distribution function of the probability of stranding is known, one can obtain the economic optimal channel width by using the following equation: $\frac{\partial C_{tot}}{\partial B} = 0$

4.4 Approach case study

In the previous paragraph a general probabilistic design method for the width of a channel has been set out. This method is applied in a case study about the IJgeul further on in the research. The width of a channel depends strongly on the natural conditions and the design vessel. The design vessel will be chosen to ensure that the IJgeul allows it and all other ships using the channel to navigate in safety. The simulator runs will be executed using this design vessel, as a result an upper boundary of the width of the IJgeul is determined.

The selection of the natural conditions under which the simulator runs will be performed is done in two ways:

1. Selection of the most extreme natural conditions under which a pilot considers the channel transit safe (see Chapter 6 through 9).

   In a deterministic design the prevailing natural conditions are used to determine the required width for the design vessel. Therefore the most extreme conditions under which the channel transit is considered to be safe, have been selected to perform simulator runs. First a total of 1,000 natural conditions have been generated. Hereafter the 25 most extreme conditions, under which a channel transit is considered safe, were selected. Three natural conditions from the extreme conditions have been selected and real time runs have been performed for these conditions.

2. Selection of natural conditions which represent the weather pattern for a long period of time (see paragraph 9.2.4).

   In order to come up with a probabilistic design of the channel width also the frequencies of the natural conditions have to be taken into account. It is assumed that a total of 100 natural conditions give a good representation of a weather pattern. The outcome is a probabilistic design of the width of the IJgeul for the design vessel.

5. Site conditions IJmuiden

5.1 Introduction

The probabilistic design method treated in Chapter 4 is applied in a case study about the IJgeul in the rest of this research. The IJgeul is the entrance channel to the harbour of IJmuiden, in figure 5-1 the location of IJmuiden is plotted. This Chapter starts summarising the site conditions near the location.

Figure 5-1 North sea

5.2 Bathymetry IJgeul

The length of the IJgeul is 23,000 m. The channel has an azimuth of 100.5°, and a width of 450 m on the sea bottom. The minimum depth of the IJgeul is MSL -18.6 m. In figure 5-2 the approach area to and the IJgeul itself are shown.

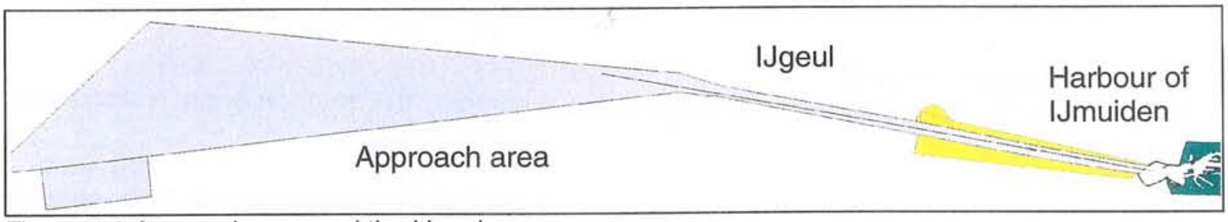


Figure 5-2 Approach area and the IJgeul

5.3 Natural conditions

5.3.1 Wind climate IJmuiden

Wind affects the ship in three different ways;

- directly
- by generating short waves
- by influencing the current

Direct influence
Wind will affect a ship at all speeds, but will have its greatest affect at low ship speeds. Container vessels have a large wind area, on the other hand bulk carriers have a small stationary freeboard and as a result a smaller wind area.

Generating short waves
Wind generates short waves at the place and time of observation, the height and period of these waves can be estimated by using the following equations produced by Groen and Dorrestein.

$$\tilde{F} = g \cdot \frac{F}{U^2} \quad (16)$$

$$\tilde{H} = g \cdot \frac{H}{U^2} \quad (17)$$

$$\tilde{T} = g \cdot \frac{T}{U} \quad (18)$$

$$\tilde{H} = 0.24 \cdot \tanh\left(0.015 \cdot \tilde{F}^{0.45}\right) \quad \text{for } \tilde{F} > 10 \quad (19)$$

$$\tilde{T} = 0.502 \cdot \tilde{F}^{0.225} \quad \text{for } 10 < \tilde{F} < 400 \quad (20)$$

$$\tilde{T} = 2 \cdot \pi \cdot \tanh\left(0.0345 \cdot \tilde{F}^{0.37}\right) \quad \text{for } \tilde{F} > 400 \quad (21)$$

where H is the significant wave height [m]
$\tilde{H}$ is the non-dimensional significant wave height
T is the wave period [sec]
$\tilde{T}$ is the non-dimensional wave period
F is the fetch length [m]
$\tilde{F}$ is the non-dimensional fetch length
g is the gravitational acceleration [m/sec^2]
U is the wind velocity [m/sec]

Affect on current velocity
Furthermore the wind also influences the current velocity, this phenomenon is discussed in paragraph 5.3.2.

In figure 5-3 the wind velocity and direction near the IJgeul is plotted against its frequency of occurrence.

Maximum flood velocity	circa 1.15 m/sec (during average tide)
Duration ebb current	circa 3h after HW until circa 2h 45m before the next HW
Maximum ebb current	circa 4h 45m after HW
Maximum ebb velocity	circa 0.83 m/sec (during average tide)

The horizontal tide is also influenced by the wind:

- South-western wind results in an extension of the duration of the flood tide as well as an increase in current velocity. The ebb tide is shortened and its current velocity is reduced by this wind condition.
- Northern wind results in an extension of the duration of the ebb tide as well as an increase in current velocity. The flood tide is shortened and its current velocity is reduced by this wind condition.
- Eastern wind results in a shorter period of the flood current.

The horizontal tide near IJmuiden has a period of 12 hrs 25 min. Usually the current patterns of the tide are given with respect to High Water (HW). Figure 5-4 shows an example of the astronomic current pattern during spring tide, 3 hours before HW. The web page of Nautilus [ref. i] presents current patterns for the three moon phases (spring-, average- and neap tide) of 6 hours before HW to 6 hours after HW with an interval of one hour.

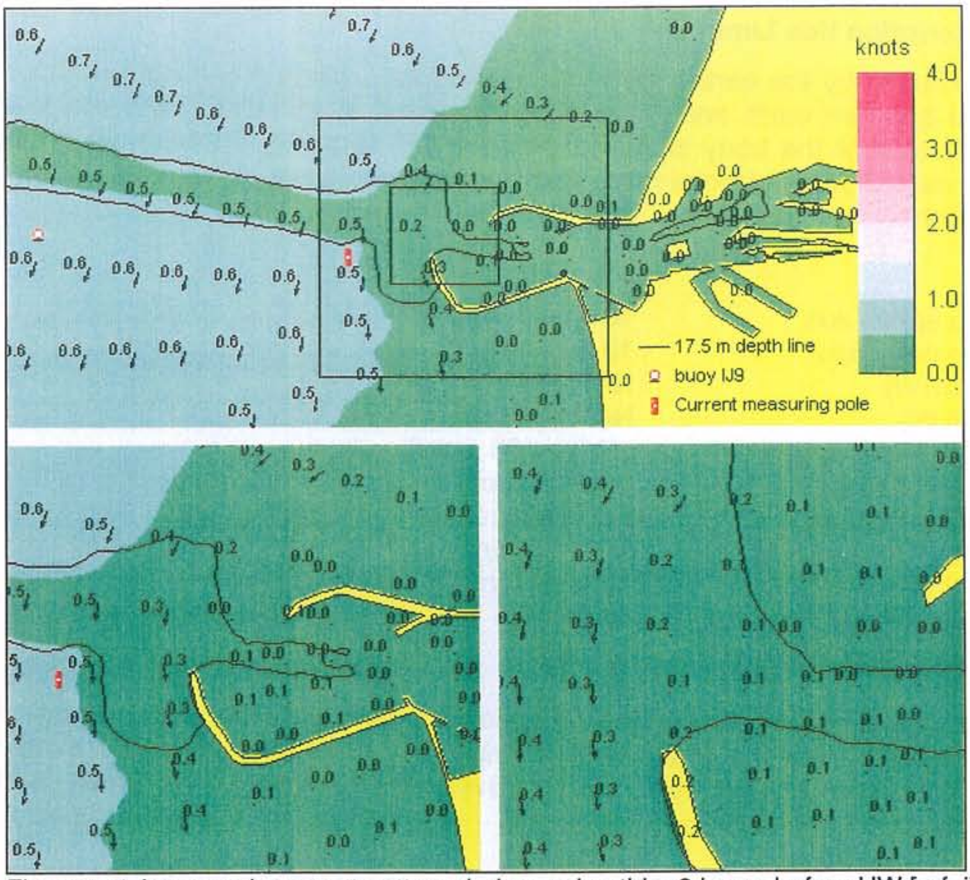
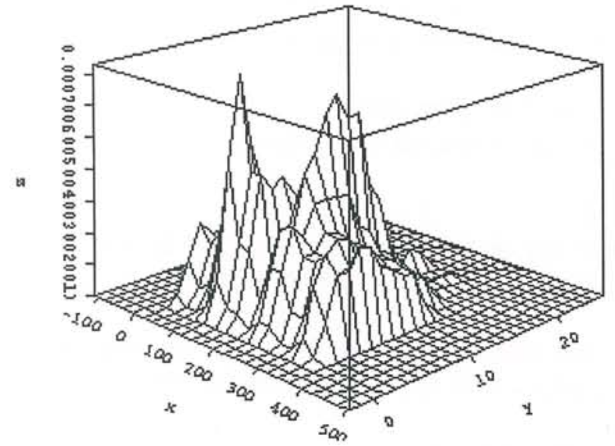


Figure 5-4 Astronomic current pattern during spring tide, 3 hours before HW [ref. i]

The astronomic current pattern is influenced by the prevailing tide and the wind conditions. These influences were studied by D. Broers in her graduation research. Tables 5-1 and 5-2 were retrieved from her research.



x: wind direction (0-360°)
y: wind speed [m/s]
z: frequency

Figure 5-3 Kernel density graph of multivariate wind data

The wind data were obtained from Directie Noordzee - Hydro - meteo advisering IJ-geul (H.M.A.IJ.), the observations were acquired during the period 1st of January 1998 until the 23rd of November 1999. These data were transformed into a wind rose by using Matlab, the Matlab program is given in Appendix XV.1, the calculated wind rose is given in Appendix VI.

5.3.2 General description tide IJmuiden

The tidal wave is initiated by the earth's own rotation and the cycling around of the moon. Gravitational forces between earth and celestial bodies result in an uplift of the sea level (vertical tide) at the side of the body and also diametrically opposite. Furthermore it also induces horizontal water flow (horizontal tide). Both these aspects are further illustrated for the tide near IJmuiden.

Vertical tide

Average tidal range spring tide	18 dm
Average tidal range neap tide	13 dm
Mean high water (MHW)	NAP +91 cm
Mean low water (MLW)	NAP -74 cm
Mean high water (MHW) springs	NAP + 106 cm
Mean low water (MLW) springs	NAP -76 cm
Mean lower low water (MLLW)	NAP -95 cm
Mean high water (MHW) neap tide	NAP +70 cm
Mean low water (MLW) neap tide	NAP -68 cm
Average duration water level rise	4h 22m
Average duration water level descent	8h 03m

The vertical tide is influenced by meteorological conditions such as wind and atmospheric pressure. During western wind the water level will rise and it will descent during eastern wind. During low atmospheric pressure the water level will rise, during high atmospheric pressure it will descent.

Horizontal tide

The flood current near IJmuiden has a northward direction, the ebb current has a southward direction.

Turn of the tide	circa 2h 45m before HW and circa 3h after HW
Duration flood current	circa 2h 45m before HW until circa 3h after HW
Maximum flood current	circa ½h before HW

Table 5-1 Maximum current velocities (C_v) at spring tide during flood [ref. 15]

		Astronomic tide	Wind N 10 m/sec	Wind SW 14 m/sec
6-1-1996	15:30-16:00	0.84 m/sec	0.75 m/sec	1.13 m/sec
7-1-1996	04:00-04:20	0.83 m/sec	0.74 m/sec	1.10 m/sec
7-1-1996	16:10-16:40	0.88 m/sec	0.79 m/sec	1.16 m/sec
8-1-1996	04:30-04:50	0.85 m/sec	0.76 m/sec	1.11 m/sec
8-1-1996	16:40-17:00	0.91 m/sec	0.81 m/sec	1.18 m/sec

Table 5-2 Maximum current velocities (C_v) at spring tide during ebb [ref. 15]

		Astronomic tide	Wind N 10 m/sec	Wind SW 14 m/sec
6-1-1996	21:40-21:50	-0.82 m/sec	-0.89 m/sec	-0.50 m/sec
7-1-1996	09:50-10:00	-0.84 m/sec	-0.91 m/sec	-0.50 m/sec
7-1-1996	22:10-22:20	-0.84 m/sec	-0.91 m/sec	-0.53 m/sec
8-1-1996	10:20-10:30	-0.85 m/sec	-0.92 m/sec	-0.54 m/sec
8-1-1996	22:10-22:50	-0.84 m/sec	-0.91 m/sec	-0.55 m/sec

In Appendix IV an attempt has been made to use these tables to come up with a connection between the current velocities during northern wind 10 m/sec or south-western wind 14 m/sec on the one hand and the astronomic current velocities on the other hand (see table 5-3).

Table 5-3 Ratio of current vel. with wind influence and astronomic C_v during spring tide

	Astronomic tide	Wind N 10 m/sec	Wind SW 14 m/sec
Flood	1	0.89	1.32
Ebb	1	1.08	0.63

The assertions of the wind influence on the current velocity are confirmed by the data from table 5-1, 5-2 and 5-3. For instance one can clearly see that during northern wind the current velocity during ebb tide increases.

The values in table 5-3 are only valid if the moon phase is spring tide. Table 5-4 lists the factors for converting the ratios of current velocities to the average- and neap tide conditions [ref. 15].

Table 5-4 Tide factors [ref. 15]

	A	B	C		
Hours with respect to HW	Velocity spring tide [m/sec]	Velocity average tide [m/sec]	Velocity neap tide [m/sec]	Factor average tide (B/A)	Factor neap tide (C/A)
0 hours	1.33	1.11	0.84	0.83	0.63

Summarising the foregoing, one can now estimate the current velocities during all moon phases (spring-, average- and neap tide) however only during northern wind 10 m/sec or south-western wind 14 m/sec. In order to be able to estimate current velocities at all wind directions and velocities, one has to come up with a relation between the current velocity on the one hand and the wind direction and velocity on the other hand. Therefore the following assumptions have been made;

- The relation current velocity versus wind velocity is assumed to be quadratic.
- The constant a has its maximum when the wind-direction is perpendicular to the entrance channel and is zero when the wind-direction is parallel to the channel because the current direction is almost always perpendicular to the channel.
- The influence of the wind on the current velocities does not vary in the nearshore zone.

These assumptions are far-reaching, therefore the outcome of the following is very questionable. The relation current velocity versus wind velocity is assumed to be quadratic (see figure 5-5) which results in the following equation;

$$F = a \cdot W_v^2 + 1 \qquad (22)$$

where F is the ratio current velocity with wind influence to astronomic current velocity
W_v is the wind velocity [m/sec]
a is a constant which can be estimated by using table 5-3

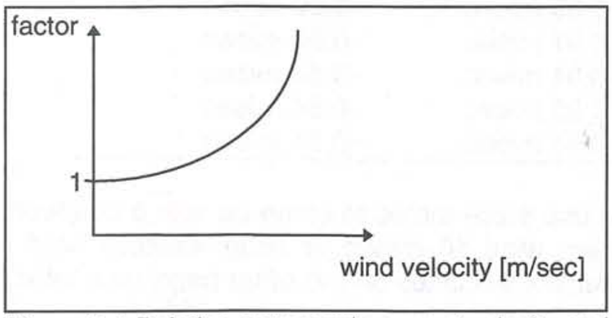


Figure 5-5 Relation astronomic current velocity and current velocity with wind influence

In table 5-5 the values of a are given for the two wind conditions for both flood as well as ebb tide, the values are derived from table 5-3.

Table 5-5 Constant a

	Wind N 10 m/sec	Wind SW 14 m/sec
Flood	-1.1·E-3	1.6·E-3
Ebb	8·E-4	-1.9·E-3

Subsequently the relation between the wind-direction and the factor a has to be determined. As stated above the assumption has been made that the constant a has its maximum when the wind-direction is perpendicular to the entrance channel and is zero when the wind-direction is parallel to the channel. The IJgeul has an azimuth of 100.5° as can be seen in figure 5-6.

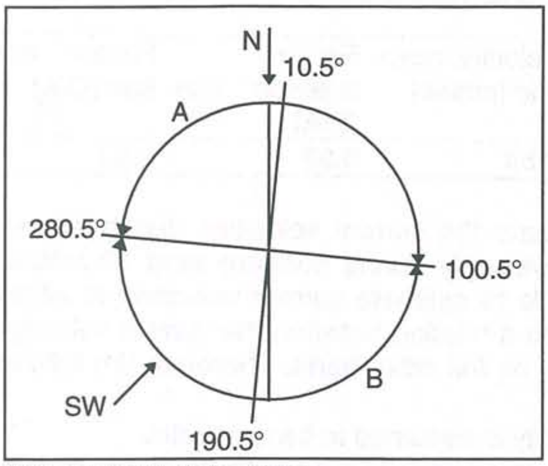


Figure 5-6 Wind directions

The extremes of a (perpendicular to the IJgeul) can now be determined for the various conditions (see figure 5-7 and 5-8).

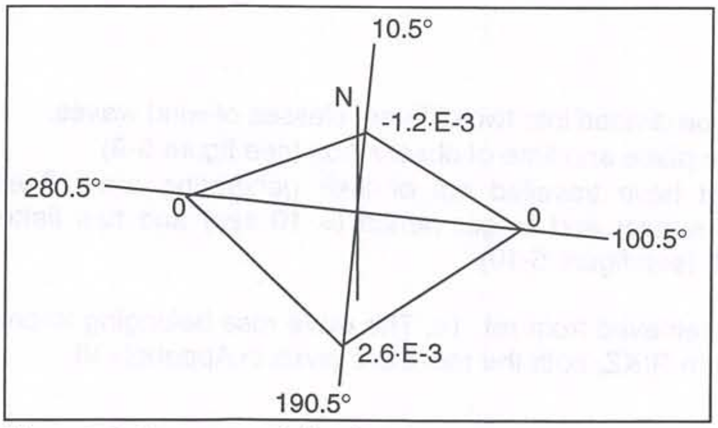


Figure 5-7 Constant a during flood

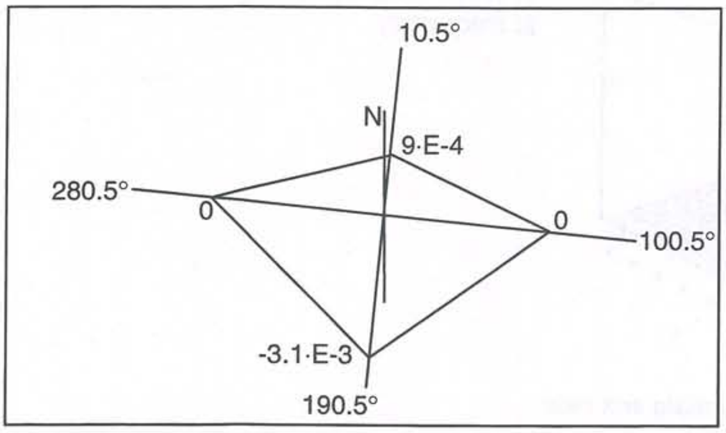


Figure 5-8 Constant a during ebb

As already stated earlier not only the wind influences the current velocities but the tide also does. Subsequently equation (24) changes into;

$$F = \left(a \cdot W_v^2 + 1\right) \cdot b \qquad (23)$$

where b is the tidal factor (see table 5-4)

Example
Neap tide, ebb, wind condition: S 9 m/sec

$$a = (180 - 100.5) \cdot \frac{-0.0031}{(190.5 - 100.5)} \approx -0.0027 \qquad (24)$$

$$b = 0.63 \qquad (25)$$

$$F = \left(-0.0027 \cdot 9^2 + 1\right) \cdot 0.63 \approx 0.49 \qquad (26)$$

In total 13 current pattern files from 6 hours before HW to 6 hours after HW during astronomic spring tide were obtained from Alkyon. These current patterns are based on the actual current velocities on 31/1998 12:00 until 1/2/1998 00:00 with an interval of 1 hour, plots of these current patterns are given in Appendix V.

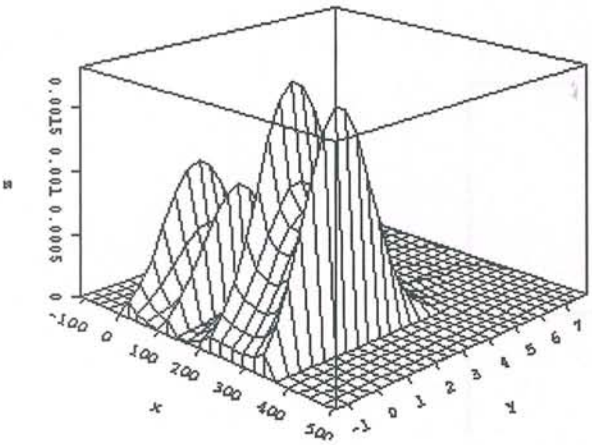
As stated above totally 13 current pattern files were obtained from Alkyon valid for astronomic spring tide. The factor F calculated above is inserted in the file, the current velocity in every grid point is multiplied by F. Therefore the current file is obtained belonging for the time of observation (-6 hours before to 6 hours after HW), the tide and the wind condition.

5.3.3 Wave climate IJmuiden

The wave climate near IJmuiden can be divided into two different classes of wind waves.

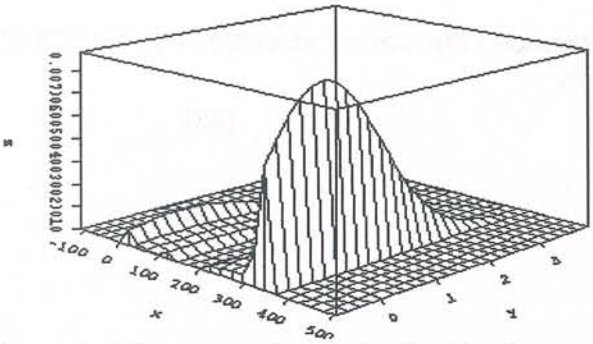
- Seas; waves caused by wind at the place and time of observation (see figure 5-9).
- Swell; wind-generated waves that have travelled out of their generating area. Swell characteristically exhibits a more regular and longer period (> 10 sec) and has flatter crests than waves within their fetch (see figure 5-10).

The wave rose of sea and swell was retrieved from ref. 14. The wave rose belonging to only swell is obtained from Mr. Roskam from RIKZ, both the roses are given in Appendix VI.



x: wave direction (0-360°)
y: wave height [m]
z: frequency

Figure 5-9 Kernel density graph of multivariate sea data



x: wave direction (0-360°)
y: wave height [m]
z: frequency

Figure 5-10 Kernel density graph of multivariate swell data

In figure 5-9 and 5-10 the sea wave height and its direction respectively the swell wave height and its direction is plotted against its frequency of occurrence.

The movement of a large ship is merely influenced by waves with a wave length equal or larger than the length of the vessel. This is only the case with swell, this can be proven by using equation (27). Subsequently hereafter attention will only be paid to this wave class.

$$L_0 = \frac{g \cdot T^2}{2 \cdot \pi} \qquad (27)$$

where L_0 is the wave-length on open sea
g is the gravitational acceleration
T is the period of the wave

The swell data given in Appendix VI are valid on open sea. When waves travel from deep water into shallower water, some significant changes occur due to refraction, diffraction, shoaling and reflection. When waves approach the shore, the wave celerity reduces. Next to that the wave height increases due to shoaling. Finally the waves approach the stage of breaking, either due to a high steepness (H/L) or due to shallow water depth (H/h). Theoretical limits are $H/L < 0.14$ and $H/h < 0.78$. In the case of swell the wave will not break because of its steepness, as its crest is very flat, and the wave will not break due to shallow water as the height of the wave is in 97% of the cases less than one meter. Therefore the breaking of the waves is not further incorporated in the case study.

5.3.4 Water level

The water levels differ during spring, average or neap tide as can be seen in paragraph 5.3.2. In table 5-6 the ratio of the water levels of average and neap tide in relation to spring tide is given.

Table 5-6 Factor water level

	High Water	Low Water
Average tide	MHW/ MHW spring = 0.86	MLW/ MLW spring = 0.97
Neap tide	MHW neap/ MHW spring = 0.66	MLW neap/ MLW spring = 0.89

6. Simulator input

6.1 Introduction

In the previous Chapter the site conditions near IJmuiden were discussed. As already stated in paragraph 4.2.1 the simulator program NAVSIM will be used to perform channel navigation transits. The outcome of these transits will be transferred into a probabilistic design of the width of the IJgeul. This Chapter deals with the input files for the simulator program NAVSIM.

As stated in paragraph 5.2 the total length of the IJgeul is 23,000 m. The channel navigation runs for this research will be executed over a total length of approximately 6.25 km.

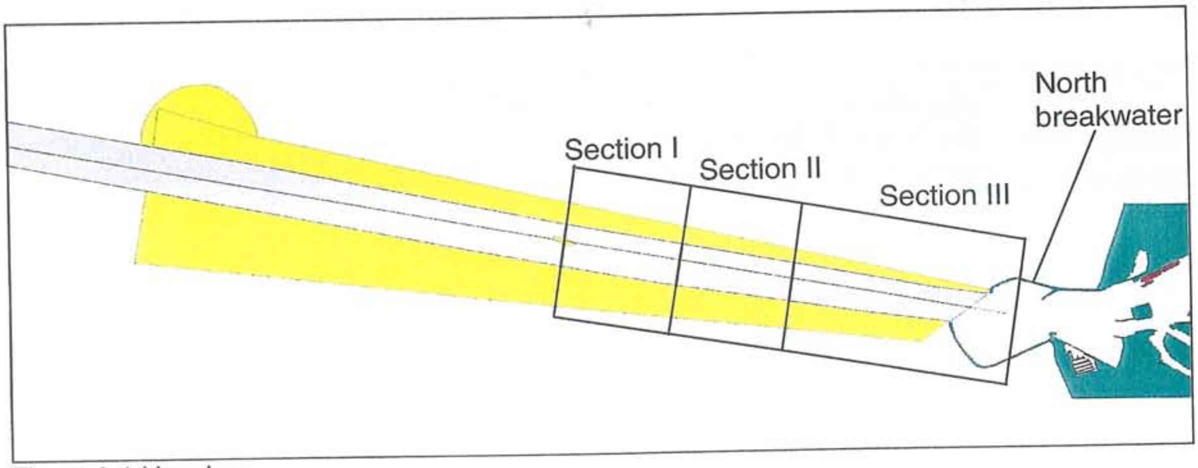


Figure 6-1 IJgeul

The track is divided into three sections (see figure 6-1). The vessel starts in the centre of the channel at the beginning of section I, the total length of this section is approximately 1.5 km. The ship sails in section I with an engine capacity of 80%. In section II (1.5 km) the ship sails with a power capacity of 60%, in the last section (3.2 km) it sails at 50% of its engine capacity.

6.2 Grid

NAVSIM applies an earth-fixed co-ordinate system, the origin of the system is in Paris (France). A grid can be defined by giving the co-ordinates of the origin of the grid (x_0 and y_0), the grid-cell size in x- and y-direction and the number of points in x- (N_x) and y-direction (N_y). In table 6-1 the grids and its specifications are given which have been inserted in NAVSIM.

Table 6-1 Grid data

	Bottom- and current grid	Wind- and Swell grid
Origin in RD co-ordinates	(70,000 , 497,500)	(70,000 , 497,000)
Cell size x-dir. [m]	75	35,000
Cell size y-dir. [m]	75	8,000
N_x	435	2
N_y	100	2
Total number of grid points	43,500	4

The data of the bottom grid file are given in respect to Mean Sea Level, the file was obtained from Alkyon. For more details see paragraph 5.2.

6.3 Natural conditions

6.3.1 Statistical description of the conditions

The frequencies of the wind-, wave- and swell direction classes have been fitted using the program Bestfit, the results are given in Appendix IX. For swell the direction classes in the range 30-210° have not been taken into account as the wave height does not exceed one height class of 0.2 m.

The goal of Bestfit is to find the distribution that best fits the input data. It does not produce an absolute answer, it just identifies the distribution that is most likely to have produced the data. For a given distribution, Bestfit varies the parameters of the function in order to optimise the goodness of fit.

Example

In this example a distribution function is fitted through the cumulative frequency of the wind velocity belonging to the wind direction class 300-330°. The cumulative frequencies of the velocity (table 6-2) are first calculated and subsequently the data are inserted in Bestfit.

Table 6-2 Cumulative frequency distribution of wind vel. of the direction class 300-330°

Wind velocity [m/sec]	Cumulative frequency
2.5	0.066
5	0.283
7.5	0.533
10	0.734
12.5	0.876
15	0.961
17.5	0.993
20	1

Bestfit comes up with a Weibull distribution, see also figure 6-2;

$$F(x) = 1 - e^{-\left[\frac{x}{\beta}\right]^{\alpha}} \qquad (28)$$

where $\alpha = 2.09$
$\beta = 8.74$

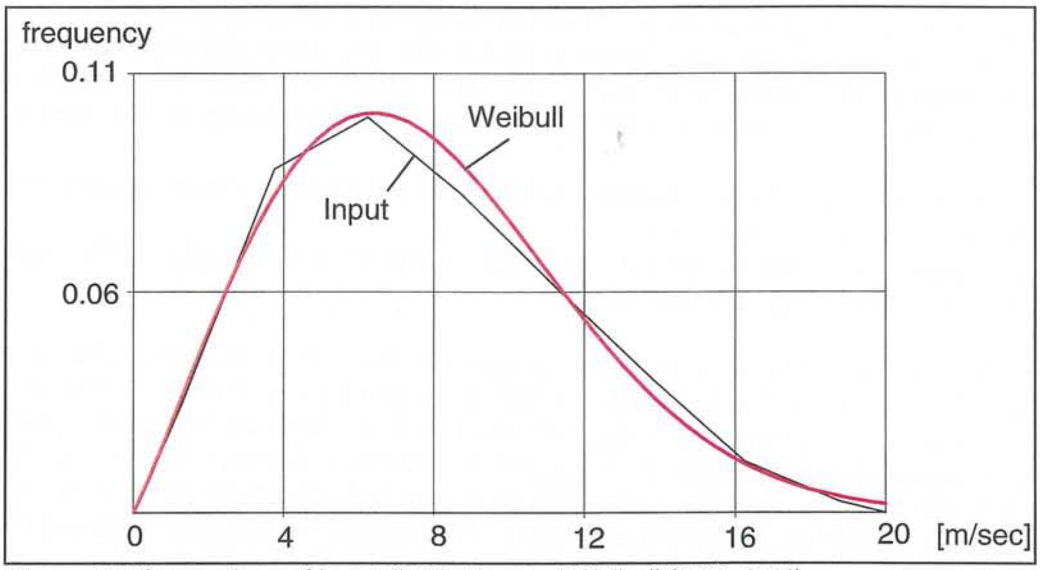


Figure 6-2 Comparison of input distribution and Weibull (2.09, 8.74)

6.3.2 Generate random condition

In Matlab four programs (see Appendix XV.2) are written for the random generation of natural conditions for a run, namely:

- Generate
- Current
- Wind
- Swell

Generate
In this program all the input files of the numerical distribution functions are read. Subsequently it executes the programs, current, wind and swell a thousand times.

Current
A moon and tidal phase is generated, it is assumed that average tide occurs in 50% of the cases, while spring and neap tide both occur in 25% of the cases. The tidal phase results in a belonging current pattern file (see paragraph 5.3.2), which is used as input file for NAVSIM.

Wind
The wind velocity and direction is generated, subsequently the factor F is determined (see paragraph 5.3.2). The factor is inserted in the current pattern file in NAVSIM. Also the water level just before the harbour entrance is calculated. The wind condition is taken constant over the whole grid.

Swell
The wave height and direction of swell is generated, the wind waves are not taken into account as already stated in paragraph 5.3.3. The correlation between wind at the place and time of observation and swell is assumed to be zero, however in reality this is not the case. The swell condition is also taken constant over the grid, the breaking of the waves is not incorporated as stated in paragraph 5.3.3.

6.3.3 Selecting natural conditions

First a number of test runs have been performed, the analysis of these simulation runs permitted the evaluation of wind-, current- and swell conditions. Then it was possible to assess the limiting weather conditions for the 175,000 dwt bulk carrier. The effect of swell on the ship seemed to be of minor importance, however wind and especially current influences the ship's behaviour to a great extend. A channel transit with a current velocity greater than 0.6 m/sec was considered unsafe. Self-evident the bulk carrier can only sail through the channel when the depth of it is large enough, this resulted in the following natural selection criteria.

- The maximum current velocity (C_v, velocity just before the harbour entrance) has to be smaller than 0.6 m/sec (horizontal tide)
- The required water level (WL) is larger than MSL +0.05 m (the draught of the vessel including 15% keel clearance) (vertical tide)

Totally 1,000 different conditions have been generated, here it is assumed that these conditions give a good representation of the weather for a long period of time. Further in the research the collection of these 1,000 natural conditions is referred to as the overall condition set. Subsequently this overall set of natural conditions is divided into two sets. One set complying to the natural selection criteria stated above and the other set comprising of the remainder of the overall set of natural conditions. The sets will be referred to as set I and set II respectively.

As can be seen in 40% of the time a channel transit of the bulk carrier is possible (natural condition set I). Self-evident in 60% of the time a channel transit is impossible because either the current velocity is greater than 0.6 m/sec or the water level is less than MSL +0.05 m (natural condition set II). In table 6-3 the percentages of time are given for the selection criteria.

Table 6-3 Percentage of time of the natural conditions

			Condition set I
Criteria	$C_v < 0.6$ m/sec	WL > MSL +0.05 m	$C_v < 0.6$ m/sec & WL > MSL +0.05 m
Percentage of time	90%	50%	40%

As stated in paragraph 4.4 first the most extreme natural conditions under which a pilot considers the channel transit safe have to be selected. The natural conditions set ! comprises of conditions during which a channel transit is safe. In order to obtain the extreme conditions from this set an extra criterion is applied; $C_v > 0.45$ m/sec. This resulted in a division of set I as can be seen in figure 6-3. The natural condition set I.2 consists of the 51 most extreme natural conditions of set I, these conditions are listed in table 6-4.

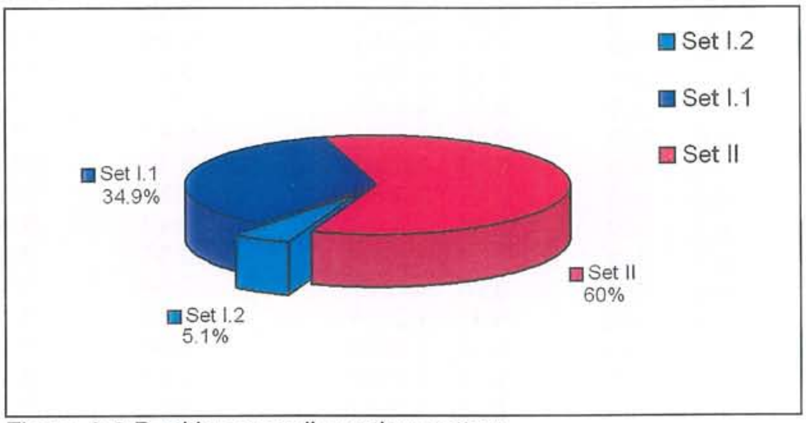


Figure 6-3 Partition overall weather pattern

Table 6-4 Generated extreme natural conditions (set I.2)

run	tide	hours ±HW	wind dir. [°]	wind vel. [m/sec]	swell dir. [°]	swell height [m]	F [-]	max. current velocity [m/sec]	water level (MSL) [m]
1	neap	-1	238	9.8	14	0.13	0.7025	0.5	0.37
2	average	+1	291	8.7	341	0.33	0.8208	0.49	0.89
3	spring	+5	302	7.3	335	0.19	1.0117	0.54	0.08
4	spring	+5	273	16.6	265	0.12	0.932	0.49	0.08
5	average	+1	328	11	333	0.31	0.7663	0.46	0.89
6	spring	+2	211	11.7	347	0.27	1.2725	0.53	0.69
7	average	+1	29	8.3	304	0.32	0.7763	0.46	0.89
8	average	+1	278	7.8	340	0.02	0.8323	0.5	0.89
9	average	+5	329	15.7	239	0.24	0.9302	0.49	0.08
10	average	+1	296	17.4	340	0.08	0.7778	0.46	0.89
11	average	+1	243	9.3	353	0.27	0.9068	0.54	0.89
12	neap	+1	195	14.8	331	0.1	0.9698	0.58	0.71
13	neap	+1	215	14.8	346	0.12	0.8913	0.53	0.71
14	average	+1	253	13.7	337	0.36	0.9505	0.57	0.89
15	spring	+5	339	7	355	0.37	1.0292	0.55	0.08
16	spring	+1	322	9.4	222	0.3	0.951	0.57	1.01
17	average	+1	275	7.1	326	0.07	0.8361	0.5	0.89
18	average	-1	305	12.6	352	0.07	0.7853	0.56	0.47
19	average	-1	86	9	0	0.03	0.8173	0.58	0.47
20	average	+1	212	9.1	339	0.1	0.9651	0.58	0.89
21	average	+1	63	10.4	331	1.12	0.7855	0.47	0.89
22	average	-1	271	7.8	349	0.24	0.8423	0.6	0.47
23	average	+5	13	8.5	340	0.05	0.8824	0.47	0.08
24	spring	+5	301	11	336	0.72	1.0255	0.54	0.08
25	spring	+1	336	7.8	349	0.11	0.9543	0.57	1.01
26	spring	+2	214	8.5	309	0.35	1.14	0.48	0.69
27	neap	+0	295	8.7	355	0.11	0.6207	0.54	0.85
28	neap	+0	100	8.6	348	0.08	0.6307	0.55	0.85
29	spring	+2	241	17.4	343	0.11	1.3416	0.56	0.69
30	spring	+5	348	11.9	345	1.16	1.0963	0.58	0.08
31	neap	+0	85	8.6	335	0.13	0.6206	0.54	0.85
32	neap	-1	216	8.8	315	0.17	0.7197	0.51	0.37
33	neap	-1	270	8.5	312	0.06	0.6433	0.46	0.37
34	average	+1	70	15	344	0.29	0.7565	0.45	0.89
35	neap	-1	248	10.3	355	0.27	0.6918	0.49	0.37
36	spring	+2	218	8.4	360	0.35	1.1252	0.47	0.69
37	average	+1	225	11.2	338	0.33	0.9947	0.59	0.89
38	neap	-1	246	9	345	0.29	0.6805	0.48	0.37
39	average	+5	61	9.9	325	0.18	0.8616	0.46	0.08
40	spring	+2	226	9.5	316	0.22	1.1417	0.48	0.69
41	average	+5	316	9.5	342	0.11	0.8567	0.45	0.08
42	spring	+2	216	7.6	354	0.07	1.1059	0.46	0.69
43	neap	-1	235	11.3	332	0.09	0.7337	0.52	0.37
44	neap	+0	325	8.1	14	0.16	0.6051	0.53	0.85
45	spring	+5	305	10.3	262	0.09	1.0267	0.54	0.08
46	neap	+0	147	7	346	0.21	0.6722	0.59	0.85
47	spring	+5	2	10.3	360	0.06	1.0871	0.58	0.08
48	neap	-1	222	7.3	355	0.58	0.6861	0.49	0.37
49	spring	+2	205	11.1	359	0.09	1.2692	0.53	0.69
50	spring	+2	238	11.2	354	0.16	1.1516	0.48	0.69
51	spring	+5	61	7.1	332	0.25	1.0196	0.54	0.08

6.4 Ship parameters

6.4.1 General

A forecast of the type and number of vessels in the year 2015 has been given in ref. 12. Based on this information a design vessel has to be chosen to investigate further in the case-study.

Table 6-5 Types of sea going vessels

	Classes of capacity (dwt)			
Type	I	II	III	IV
Car carrier	<5,000	<10,000	<20,000	>20,000
Multipurpose ship	<5,000	>5,000		
Bulk carrier	<30,000	<55,000	<120,000	>120,000
Chemical tanker	<5,000	<30,000	<70,000	>70,000
Container ship	<10,000 (<750 TEU)	<25,000 (<1,500 TEU)	<35,000 (<2,500 TEU)	>35,000 (>2,500 TEU)
General cargo ship	<7,500	<15,000	<20,000	>20,000
Cruise ship	<5,000	>5,000		
Gas tanker	<5,000	>5,000		
Remaining ships	<5,000	>5,000		
Reefer	<7,500	<15,000	<20,000	>20,000
Ro/Ro ship and ferry	<5,000	<10,000	<20,000	>20,000
Tanker	<5,000	<30,000	<70,000	>70,000
Dredger/ Dumper	<5,000	>5,000		

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After consultation the class IV bulk carrier was chosen as the design vessel. An assumption is made that the entrance channel will be deepened in the near future in order to receive vessels with a draught up to 60 feet (18.25 m).

Hydrodynamic coefficients of the design vessel have to be inserted in the NAVSIM simulation program. The coefficients are derived from model tests. As these model tests have not been performed for every single vessel, the exact dimensions of the design vessel have to be derived from available ships with known coefficients. Finally a 175,000 dwt bulk carrier is chosen, its dimensions and general data are presented in table 6-6.

Table 6-6 General data 175,000 dwt bulk carrier

Length over all [m]	300
Beam [m]	48.3
Draught forward [m]	16.7
Draught after [m]	16.7
Displacement [tons]	204,300
Dead weight tonnage [tons]	175,000
Engine type [-]	Diesel
Number of revolutions [rpm]	90
Service speed [kn]	16
Frontal wind area [m²]	810
Lateral wind area [m²]	2,980

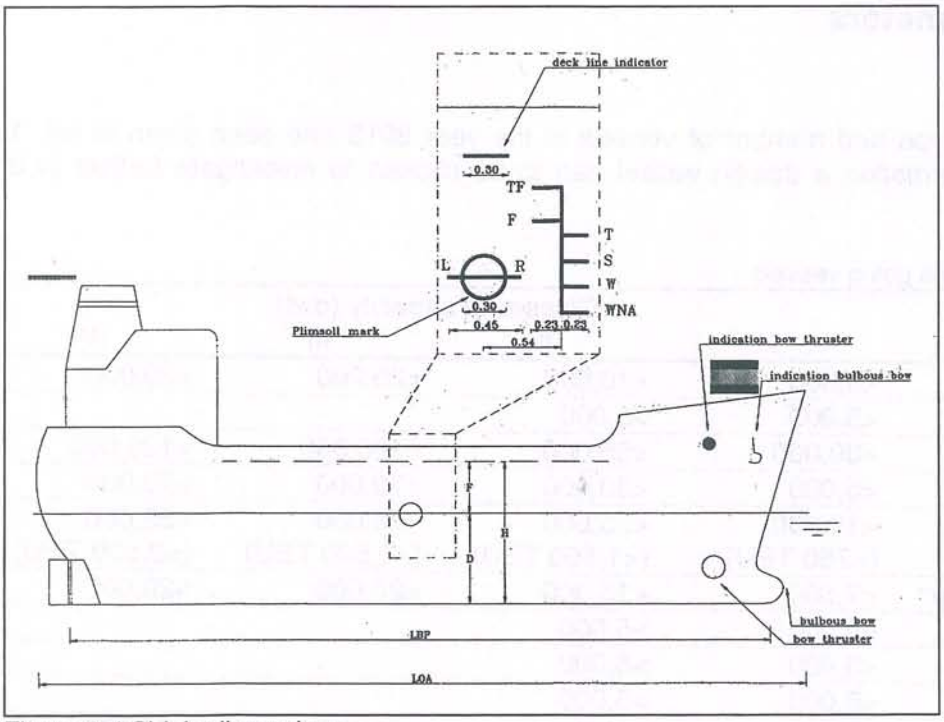

Figure 6-4 Ship's dimensions

where D is the draught [m]
LOA is the Length Over All [m]
F is the stationary freeboard [m]

Besides the manoeuvring characteristics of the ship, also wind- and wave coefficients are inserted in the NAVSIM simulation program.

6.4.2 Tug boat assistance

Usually two tug boats of 50 tons are required to tow a 175,000 dwt bulk carrier to its berthing place, the time required for tying up tugboats depends very much on the expertise of the crews and the environmental conditions. In the harbour of IJmuiden the tug boats tie up when the vessel passes the old breakwater (see figure 6-5). The runs for this research will already be terminated just after the North breakwater, therefore no tug boat assistance is simulated.

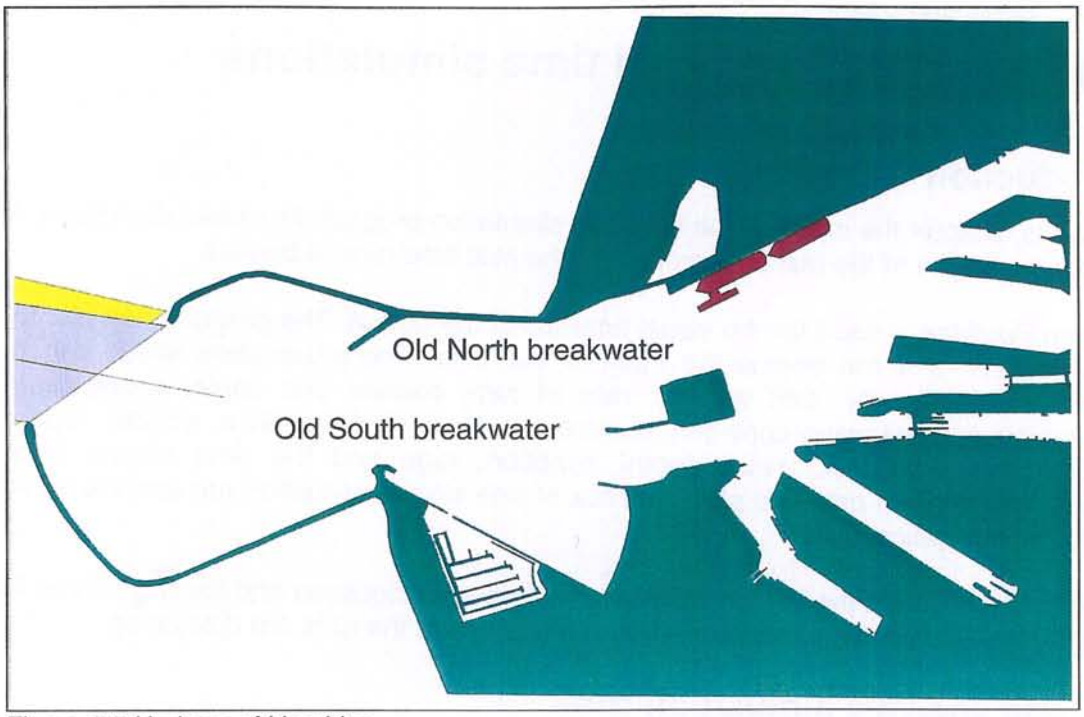

Figure 6-5 Harbour of IJmuiden

6.5 Auto pilot settings

6.5.1 Track

The track is composed of straight lines and circle bends. The auto-pilot tries to manoeuvre the vessel as accurate as possible on the intended track line. In the simulations the track was set out as the centre line of the channel.

Table 6-7 Pairs of x- and y co-ordinates of the way points

nr.	x_i [m]	y_i [m]
1	70,000	502,881
2	85,000	500,101
3	93,195	498,582
4	94,670	498,308
5	96,145	498,035
6	97,833	497,723

6.5.2 Anticipation distance

The anticipation distance is the part of the track which can be looked over by the auto-pilot, and is measured ahead from the origin of the ship. A large anticipation distance simulates an experienced pilot. In this research the anticipation distance is set at 1.75 times the length of the ship, 525 m.

7. Results of fast- and real time simulations

7.1 Introduction

In the previous Chapter the input for the NAVSIM simulation program has been discussed. In this Chapter the output of the fast time as well as the real time runs is treated.

The program PostMan is used for the visual analysis of the output. The program can plot the output parameters of a run versus the track or the time. The parameters which can be plotted are: ahead velocity, drift velocity, rate of turn, course/ drift angle, water depth, seawave condition, swell wave condition, current condition, wind condition, engine, rudder, bow thruster, stern thruster, water depth/ z-motion, tugs and the time versus track. Furthermore the program can also plot the track of one single navigation run and the swept path of several navigation runs.

In the following paragraph the key performance factors are discussed and limiting criteria for a safe transit are set. Subsequently the visual output plots of the runs are discussed.

7.2 Criteria analysis simulation runs

The runs fast time as well as real time have to be judged whether the channel navigation of the ship is nautical safe. A decision whether the navigation is safe or not is made on the basis of the following criteria.

- Rudder angle
- Drift angle
- Power burst
- Deviation from the desired track
- Speed at entrance harbour

A run can be considered feasible (F), critical (C) or unacceptable (U) for each criterion. The worst outcome of all the criteria determines whether the channel navigation is safe. All the criteria have been evaluated with Mr. Brak of Loodswezen IJmuiden.

Rudder angle

The maximum rudder angle is 35°, however sailing with a rudder angle of more than 20° over a long distance is considered undesirable from safety point of view. The ability to react to unexpected events decreases with increasing rudder angle.

Table 7-1 Rudder angle criterion

Sailing distance with a rudder angle > 20°	Judgement
0 - 400 m	F
400 - 550 m	C
> 550 m	U

Drift angle

The ship has to maintain an angle with the channel axis in order to counteract the forces due to current and wind. This drift angle is limited to about 20° because for greater angles the rudder control reduces too much. However sailing with a drift angle greater than 15° is considered undesirable by pilots, therefore table 7-2 is handled to judge the safety of the channel navigation.

Table 7-2 Drift angle criterion

Drift angle	Judgement
0 - 15°	F
15 - 20°	C
> 20°	U

Power burst
A power burst is only allowed when the ship is sailing in the harbour entrance. If a ship is sailing with maximum rudder angle in combination with a power burst it can not respond to unexpected situations as it already is sailing in its limit state. A second disadvantage is the increased entrance speed of the ship through which it is more difficult to slow down in time. For these reasons a power burst for a long distance is considered undesirable, see table 7-3.

Table 7-3 Power burst criterion

Sailing distance with a power burst	Judgement
0 - ½·L	F
½·L - L	C
> L	U

where L = length of the ship (300 m)

Deviation from the desired track
The desired track is the centre line of the IJgeul which has an azimuth of 100.5°. A large deviation is considered undesirable as it may result in grounding of the ship.

Table 7-4 Deviation criterion

Deviation from the desired track	Judgement
0 - 50 m	F
50 - 100 m	C
> 100 m	U

Speed at entrance harbour
A maximum speed of the ship at the harbour entrance of 7 knots is maintained.

7.3 Analysis fast time simulation runs

7.3.1 General

As stated in paragraph 4.4 simulator runs will be performed using the most extreme natural conditions under which a pilot considers the channel transit safe. In paragraph 6.3.3 a set of 51 natural conditions (set I.2) has been selected which consists of these extreme natural conditions under which a channel transit is safe. However the feasibility of these conditions have not been judged by a pilot yet.

Fast time runs were reproduced in the model for all conditions of set I.2. These runs have been analysed using the criteria stated in paragraph 7.2, the outcome for all runs is given in Appendix X. This resulted in 25 conditions (set I.2a) which were considered either feasible or critical according to the criteria (see figure 7-1). Therefore this set of conditions can be considered as the most extreme natural conditions under which a pilot considers the channel transit safe.

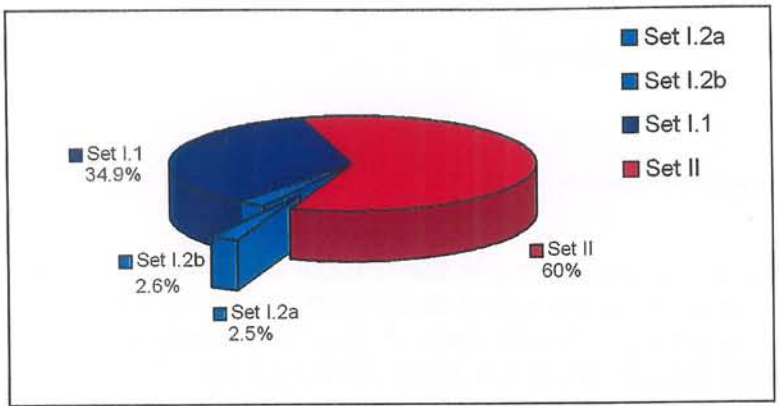

Figure 7-1 Partition feasible extreme conditions (set I.2a)

The greatest part of the unacceptable runs (set I.2b) has a drift angle greater than 20° over a length more than 550 m.

The difficulty level of a run can be concluded from the output parameters. The 25 feasible or critical runs have been ordered in level of difficulty where the most extreme condition starts with one, see table 7-5.

Table 7-5 Fast time runs (set I.2a)

			Input								Output					
run	tide	hours HW	wind dir. [°]	wind vel. [m/sec]	swell dir. [°]	swell height [m]	F [-]	max. current velocity [m/sec]	water level [m]	rudder > 20 ° [m]	power burst [m]	max. drift angle [°]	entrance speed [m/sec]	judgement	order
2	average	+1	291	8.7	341	0.33	0.8208	0.49	0.89	250	100	9	3.2	F	20
3	spring	+5	302	7.3	335	0.19	1.0117	0.54	0.08	490	0	9	3.1	C	18
4	spring	+5	273	16.6	265	0.12	0.932	0.49	0.08	510	0	8	3.2	C	15
5	average	+1	328	11	333	0.31	0.7663	0.46	0.89	200	30	8	3.2	F	23
8	average	+1	278	7.8	340	0.02	0.8323	0.5	0.89	480	130	9	3.2	C	8
10	average	+1	296	17.4	340	0.08	0.7778	0.46	0.89	540	160	10	3.4	C	4
15	spring	+5	339	7	355	0.37	1.0292	0.55	0.08	520	0	10	3.1	C	10
16	spring	+1	322	9.4	222	0.3	0.951	0.57	1.01	250	130	10	3.2	F	19
17	average	+1	275	7.1	326	0.07	0.8361	0.5	0.89	330	130	9	3.3	F	17
21	average	+1	63	10.4	331	1.12	0.7855	0.47	0.89	190	60	8	3.1	F	22
23	average	+5	13	8.5	340	0.05	0.8824	0.47	0.08	520	0	8	3.1	C	13
25	spring	+1	336	7.8	349	0.11	0.9543	0.57	1.01	290	130	10	3.2	F	14
26	spring	+2	214	8.5	309	0.35	1.14	0.48	0.69	450	100	8	3.2	C	12
28	neap	+0	100	8.6	348	0.08	0.6307	0.55	0.85	510	190	10	3.2	C	3
33	neap	-1	270	8.5	312	0.06	0.6433	0.46	0.37	500	260	9	3.3	C	2
34	average	+1	70	15	344	0.29	0.7565	0.45	0.89	180	0	8	3	F	25
36	spring	+2	218	8.4	360	0.35	1.1252	0.47	0.69	510	100	8	3.2	C	7
39	average	+5	61	9.9	325	0.18	0.8616	0.46	0.08	190	0	8	3.1	F	24
40	spring	+2	226	9.5	316	0.22	1.1417	0.48	0.69	510	130	8	3.2	C	5
41	average	+5	316	9.5	342	0.11	0.8567	0.45	0.08	490	0	8	3.1	C	16
42	spring	+2	216	7.6	354	0.07	1.1059	0.46	0.69	480	130	8	3.2	C	9
44	neap	+0	325	8.1	14	0.16	0.6051	0.53	0.85	520	200	10	3.3	C	1
45	spring	+5	305	10.3	262	0.09	1.0267	0.54	0.08	520	0	9	3.1	C	11
50	spring	+2	238	11.2	354	0.16	1.1516	0.48	0.69	510	130	8	3.2	C	6
51	spring	+5	61	7.1	332	0.25	1.0196	0.54	0.08	310	0	10	3.1	F	21

As an example the output plot of the fast time run of condition 26 is given in figure 7-2. In this figure the ship's speed, the course/ drift angle, the engine and the rudder angle is plotted versus the time. Figure 7-3 shows the belonging sailed track of the channel navigation run.

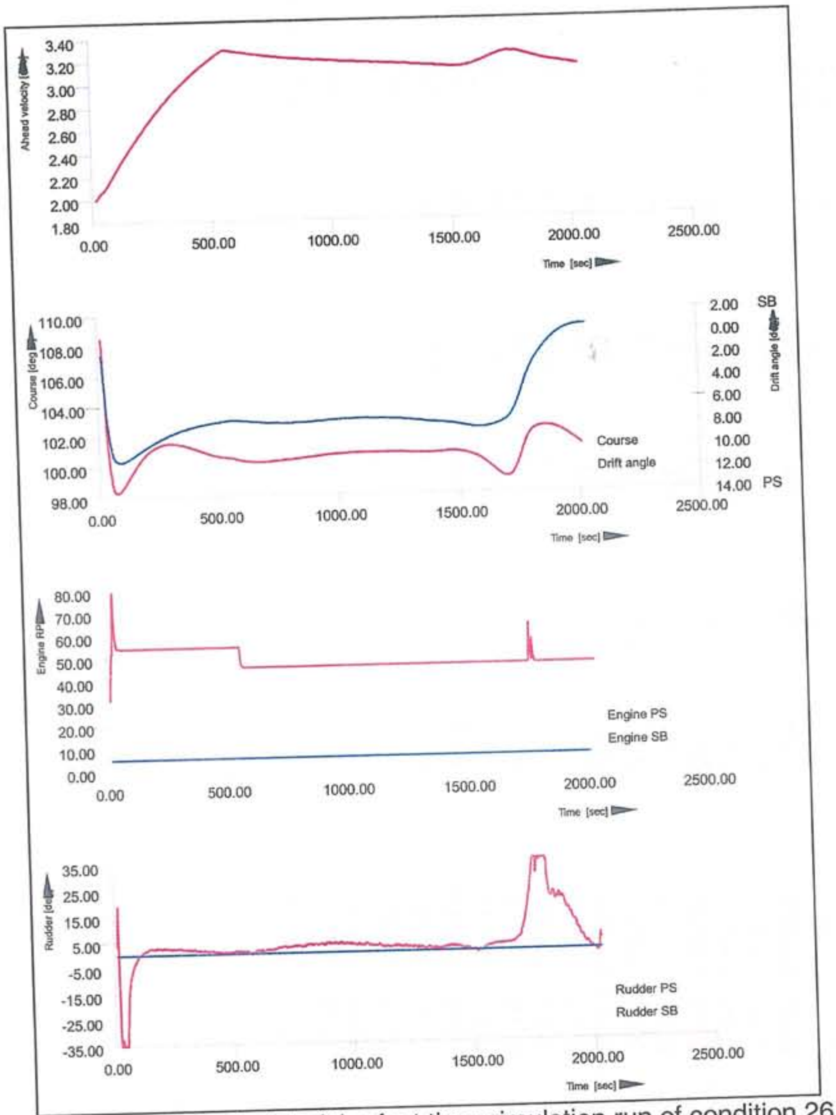

Figure 7-2 Output plot of the fast time simulation run of condition 26

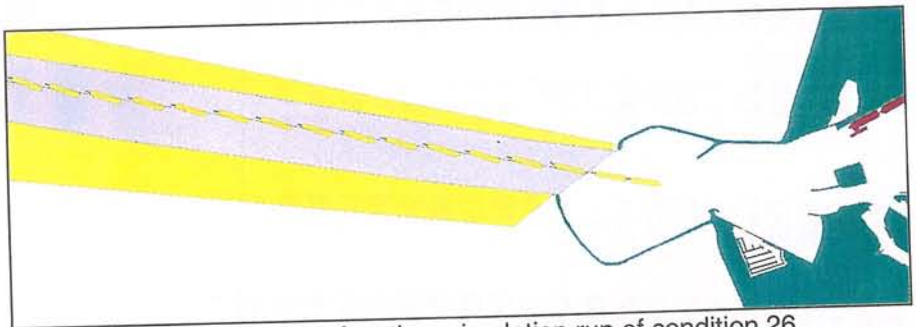

Figure 7-3 Track plot of the fast time simulation run of condition 26

It is striking that the graph of the rudder angle and the engine show a highly peaked path. In reality a pilot does not constantly adjust the rudder angle or engine power. This observation can be ascribed to the predetermined settings of the auto-pilot of the fast time model. The plot of the output parameters, the ship's speed, the course/ drift angle, the engine and the rudder angle is plotted for all runs (see Appendix XVI).

7.3.2 Description runs

The ship sails with an almost constant drift angle on the centre line of the channel until the head of the South breakwater. Upon entering the harbour the bow is moving out of the current and the moment on the ship increases, through which also the turning rate of the ship increases. The auto-pilot reacts by giving rudder in opposite direction and if necessary a power burst is given.

The maximum drift angle for all runs is equal or smaller than 11°, this is no problem for safe passage. In order to let the entrance speed be smaller than 7 knots (3.6 m/sec) the power capacity is set at 50% in the last section, this is sufficient as can be seen in Appendix X and table 7-5.

7.3.3 Selecting conditions for the execution of real time runs

Three fast time runs (feasible or critical) are selected to perform for each conditions 20 real time runs. The conditions 26 and 44 have been selected, condition 44 is considered to be an extreme condition (see table 7-5). Condition 26 is considered to be an average condition compared to all 25 natural conditions. Furthermore real time runs have been executed for condition 51. Each manoeuvring condition was repeated 20 times.

7.4 Analysis real time simulation runs

Before the actual real time simulator runs were performed, first acclimatisation runs were executed. Once the channel and the natural condition became familiar a start was made with the 'measurement' runs. The results for all real time runs are given in Appendix X.

Below the real time simulation runs of the three conditions are further elaborated. The performance factors which are checked against the various criteria (see paragraph 7.2) usually consist of:

- rudder activity, including standard deviation of rudder angle, sailing distance with a rudder angle greater than twenty degrees, number of zero crossings
- drift angle
- engine movements, including the frequency and number of power bursts
- off-track error
- speed variations
- heading variations

As can be seen in table 7-5 the sequence in level of difficulty of the conditions is the following; most difficult: condition 44, followed by condition 26, the least difficult is condition 51.

Condition 26

The number of zero crossings of the rudder angle is less than those from condition 44 but more than from condition 51. On average two engine movements were made during the runs, approximately the same as for condition 44.

Condition 44

During the entrance manoeuvre it was hard to keep to the vessel's intended track, due to the moving out of the current of the bow of the vessel. As can be seen from the output plots (see Appendix XVI) much rudder activity and engine movement was necessary to attain the intended track.

Condition 51
This condition was considered the least difficult of the three conditions according to the fast time output. This was confirmed by the real time runs.

It is striking that for all real time runs of the three conditions the distance with a rudder angle greater than twenty degrees is smaller than during the fast time run of the belonging condition. For condition 26 and 44 it was noticed that the mean sailing distance with a power burst for the real time runs is approximately equal to the outcome of the fast time runs. During the fast time run of condition 51 no power burst was given at all, however in all real time runs the engine power was increased during the entrance manoeuvre.

8. Probabilistic analysis

8.1 Introduction

In the previous Chapter the runs have been analysed on their feasibility. In this Chapter the deviation of the ship with respect to the centre line of the channel is analysed in order to be able to produce a probabilistic design of the IJgeul.

8.2 Analysis swept path

During the simulator runs the x- and y co-ordinates of the origin of the ship and the heading angle of the vessel (ψ) are tracked. Using these data the maximum absolute excursion at every position can be determined.

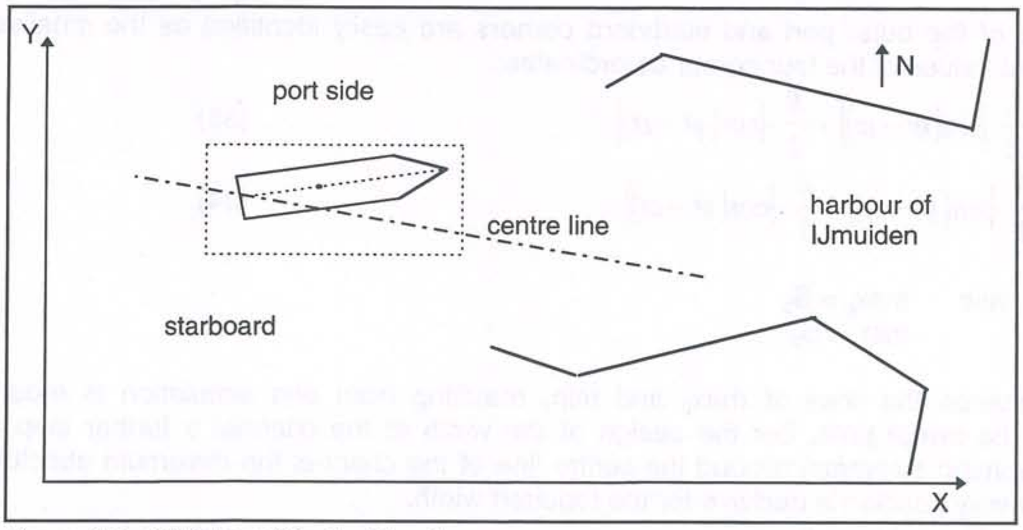

Figure 8-1.a Ship transit in the IJgeul

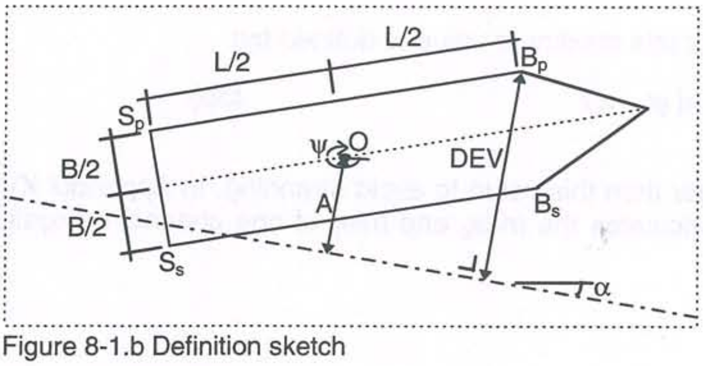

Figure 8-1.b Definition sketch

where O = origin ship
B = width ship
L = length ship
A = minimal distance, centre line channel and origin ship
DEV = maximum absolute excursion
ψ = heading angle
α = angle between the x-axis and the centre line of the IJgeul

If a vessel progresses in a channel, the positions of the four corners are of interest as already stated in Appendix II. When the position of the bow is indicated with B and the stern with S and port and starboard with the subscripts p and s, the following formula define the positions (figure 8-1.b):

$$B_s = A + \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| - \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (29)$$

$$B_p = A + \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| + \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (30)$$

$$S_s = A - \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| - \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (31)$$

$$S_p = A - \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| + \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (32)$$

The positions of the outer port and starboard corners are easily identified as the smallest and the largest values of the four corner co-ordinates:

$$\max_p = A + \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| + \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (33)$$

$$\min_s = A - \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| - \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (34)$$

where in this case $\max_p = B_p$
$\min_s = S_s$

The area between the lines of $\max_p$ and $\min_s$ resulting from one simulation is mostly indicated as the swept path. For the design of the width of the channel a further step is required. Assuming symmetry around the centre line of the channel the maximum absolute excursion at every position is decisive for the required width.

$$\max_{\max} = MAX\left(\left|\max_p\right|, \left|\min_s\right|\right) \quad (35)$$

It can be shown that the expression for this maximum value is defined by:

$$\max_{\max} = |A| + \frac{L}{2} \cdot \left|\sin(\psi - \alpha)\right| + \frac{B}{2} \cdot \left|\cos(\psi - \alpha)\right| \quad (36)$$

The half channel width should be larger than this value to avoid stranding. In Appendix XV.3 the Matlab program is given which calculates the $\max_p$ and $\min_s$ of one channel navigation run.

8.3 Analysis maximum absolute excursions

8.3.1 General

In table 8-1 the maximum excursions for the real time simulation runs are given, in Appendix XI the maximum excursions, the swept path and the average drift angle are given for each run.

Table 8-1 Maximum excursions (set I.2a) [m]

Natural condition 26				Natural condition 44				Natural condition 51			
run	max_p	min_s	max_{max}	run	max_p	min_s	max_{max}	run	max_p	min_s	max_{max}
26_1	50.31	50.97	50.97	44_1	54.33	67.68	67.68	55_2	56.46	60.40	60.40
26_2	54.33	59.69	59.69	44_2	68.16	46.23	68.16	55_4	47.83	57.69	57.69
26_3	54.66	50.36	54.66	44_3	78.97	44.90	78.97	55_5	48.16	61.97	61.97
26_5	51.89	47.43	51.89	44_8	57.12	62.90	62.90	55_6	48.23	62.43	62.43
26_8	68.30	45.35	68.30	44_10	61.15	46.88	61.15	55_7	48.22	59.59	59.59
26_9	59.37	45.65	59.37	44_11	62.15	46.51	62.15	55_8	48.45	62.24	62.24
26_10	53.76	61.01	61.01	44_12	64.74	46.75	64.74	55_9	48.56	64.37	64.37
26_11	60.34	45.24	60.34	44_13	49.88	71.58	71.58	55_10	48.75	63.51	63.51
26_13	50.33	59.93	59.93	44_14	52.74	55.52	55.52	55_11	48.59	56.70	56.70
26_14	51.11	63.23	63.23	44_16	51.37	67.95	67.95	55_12	48.40	61.66	61.66
26_15	58.02	46.92	58.02	44_17	57.05	51.19	57.05	55_13	48.42	62.16	62.16
26_17	52.95	57.21	57.21	44_18	54.29	55.38	55.38	55_14	48.45	58.53	58.53
26_18	58.10	45.24	58.10	44_19	54.39	63.22	63.22	55_15	47.76	65.07	65.07
26_19	60.32	45.35	60.32	44_20	53.52	64.53	64.53	55_16	48.32	61.89	61.89
26_20	57.39	45.06	57.39	44_21	55.78	48.36	55.78	55_17	48.33	63.14	63.14
26_21	56.72	45.14	56.72	44_22	52.69	65.30	65.30	55_18	48.40	64.17	64.17
26_22	57.04	45.28	57.04	44_23	54.29	63.99	63.99	55_19	48.34	62.78	62.78
26_23	58.22	44.83	58.22	44_24	57.30	47.67	57.30	55_20	48.31	62.97	62.97
26_24	57.56	45.40	57.56	44_25	61.80	46.72	61.80	55_21	48.37	60.38	60.38
26_25	55.12	44.88	55.12	44_26	67.32	46.55	67.32	55_22	48.36	60.74	60.74
mean	56.29	49.71	58.25		58.45	55.49	63.62		48.74	61.62	61.62

One of the items under discussion is to establish which is the most adequate distribution function for the position of the ship's sides, which define the width of the swept path. It is usual to use a Gaussian distribution, which is fitted in each section computing the mean value and deviation of the distances to the channel axis or border. However this is a symmetric distribution, which does not exactly fit in with the concept under analysis. In fact, given the presence of the pilot or captain and consequently, of their control actions, it is logical to expect that there is more tendency to go towards the centre of the channel than towards the borders, avoiding situations of risk, so less symmetrically distributions should be considered.

Secondly, the designer is interested in evaluating the position of the extreme values, linked to small exceedance probabilities. Therefore in this research the Generalised Extreme Value (GEV) p.d.f. will be fitted through the data. The GEV has three different sub-models, the Gumbel p.d.f., the Fréchet p.d.f. and the Weibull p.d.f. (see figure 8-2).

	Type I maxima (Gumbel)	Type II maxima (Fréchet)	Type III maxima (Weibull)
$F_{\underline{x}}(\xi)$	$\exp[-e^{-\alpha(\xi-u)}]$	$\exp[-(\xi/u)^{-k}]$	$\exp[-(\xi/u)^{k}]$
$f_{\underline{x}}(\xi)$	$\alpha \exp[-\alpha(\xi-u)-e^{-\alpha(\xi-u)}]$	$(k/u)(\xi/u)^{-k-1} \exp[-(\xi/u)^{-k}]$	$-(k/u)(\xi/u)^{k-1} \exp[-(-(\xi/u)^{k}]$
range	$-\infty < \xi, -\infty < u < +\infty, \alpha > 0$	$\xi, u, k > 0$	$u, \xi < 0 \quad k > 0$
$\mu_{\underline{x}}$	$\mu = u + 0{,}577/\alpha$	$\mu = u\,\Gamma(1-1/k) \quad (k>1)$	$\mu = u\,\Gamma(1+1/k)$
$\sigma_{\underline{x}}$	$\sigma = \pi/\alpha\sqrt{6}$	$\sigma^2+\mu^2 = u^2\,\Gamma(1-2/k) \quad (k>2)$	$\sigma^2+\mu^2 = u^2\,\Gamma(1+2/k)$
$x = \max y_i$ $i = 1 .. n$	$\alpha_x = \alpha_y,\ u_x = u_y + \{\ln(n)\}/\alpha$	$k_x = k_y,\ u_x = u_y\, n^{1/k_y}$	$k_x = k_y,\ u_x = u_y\, n^{-1/k_y}$

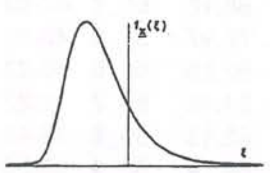
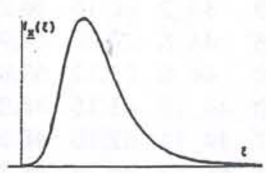
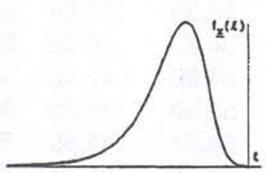

Figure 8-2 Extreme value distributions

The statistical distributions compared were the following, F(x) being the probability distribution function:

The Generalised Extreme Value (GEV) p.d.f. has been fitted through each of the three sets of 20 $\max_{max}$ data points by using the statistical software program Xtremes (see Appendix XII).

GEV $$G_\gamma(x) = \exp\left(-\left(1+\gamma\cdot\left(\frac{x-\mu}{\sigma}\right)\right)^{-1/\gamma}\right) \qquad (37)$$

By applying the approximation $(1+\gamma\cdot x)^{1/\gamma} \rightarrow \exp(x)$ as $\gamma \rightarrow 0$, one obtains the standard Gumbel df, G_0.

G_0 $$G_0(x) = \exp\left(-\exp\left(-\frac{x-\mu}{\sigma}\right)\right) \qquad (38)$$

- G_γ is a Fréchet df if $\gamma > 0$, and
- G_γ is a Weibull df if $\gamma < 0$ (see figure 8-2)

The parameter values of the GEV are given in table 8-2.

Table 8-2 Parameter values of the GEV for the $\max_{max}$ data points (set I.2a)

	Cond_26	Cond_44	Cond_51
γ	-0.173961	-0.103797	-0.556102
μ	56.7988	61.1713	61.1542
σ	3.50369	5.05844	2.37017
right endpoint	76.9394	109.905	65.4164

As can be concluded from table 8-2, all the GEV p.d.f. are of the Weibull type as $\gamma < 0$.

8.3.2 Tests

Visual check

Whether the data fit well to a Weibull p.d.f. can be visually checked. As can be seen in figure 8-3 the data plotted on Weibull paper almost transforms to a straight line. Therefore it can be concluded the data fit well to a Weibull p.d.f.

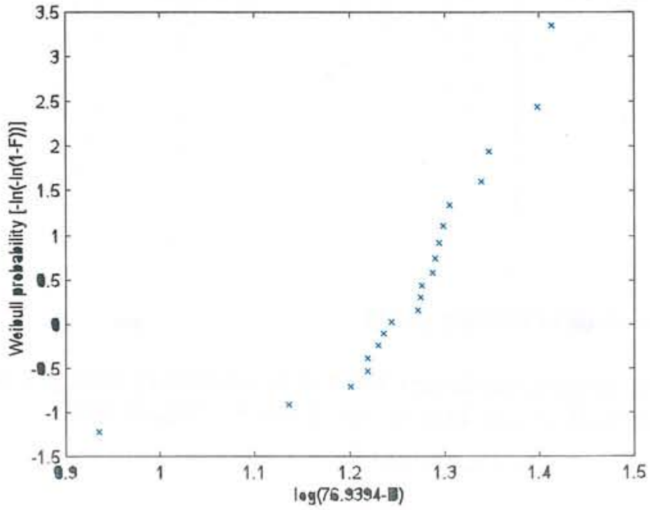

Figure 8-3.a Data of condition 26 plotted on Weibull probability paper

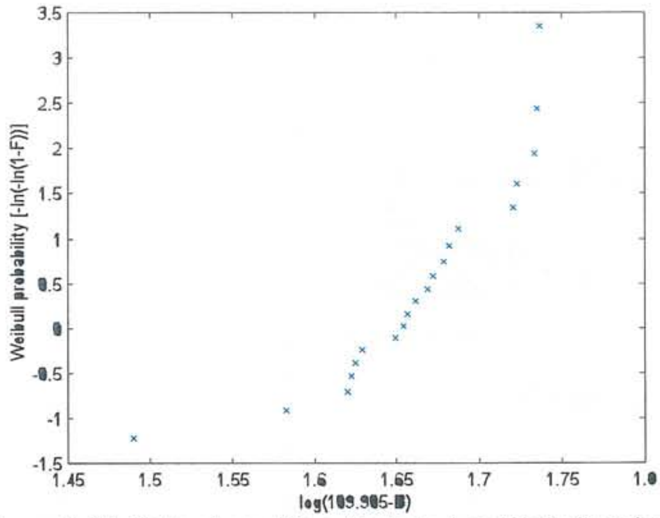

Figure 8-3.b Data of condition 44 plotted on Weibull probability paper

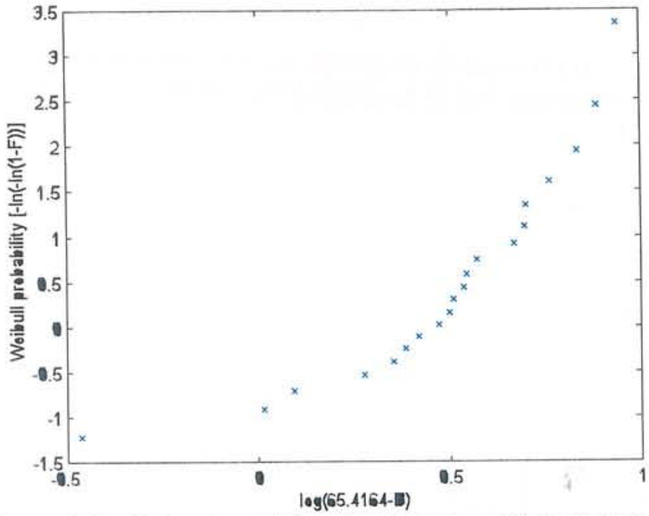

Figure 8-3.c Data of condition 51 plotted on Weibull probability paper

The data points in figure 8-3.c show the largest deviation from the imaginary straight line, this can also be seen in the kernel density plot of the data of condition 51 (figure 8-4.c).

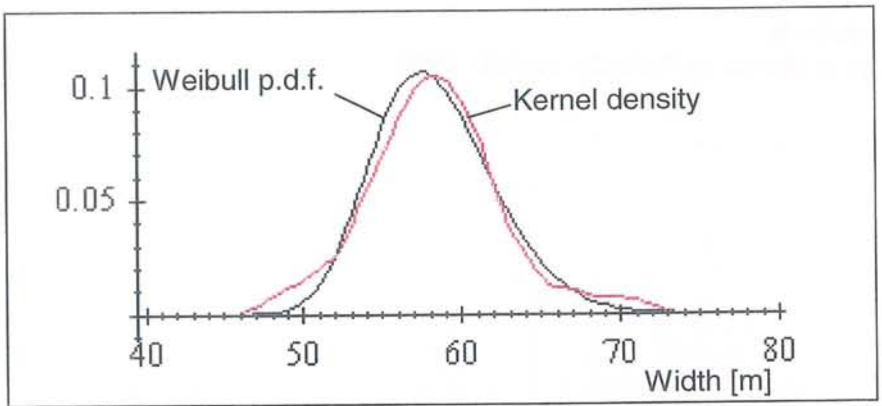

Figure 8-4.a Kernel density graph and Weibull p.d.f. of condition 26

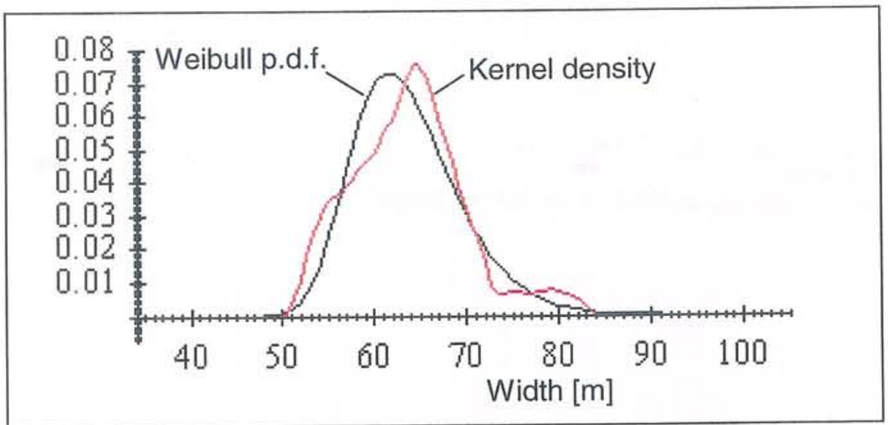

Figure 8-4.b Kernel density graph and Weibull p.d.f. of condition 44

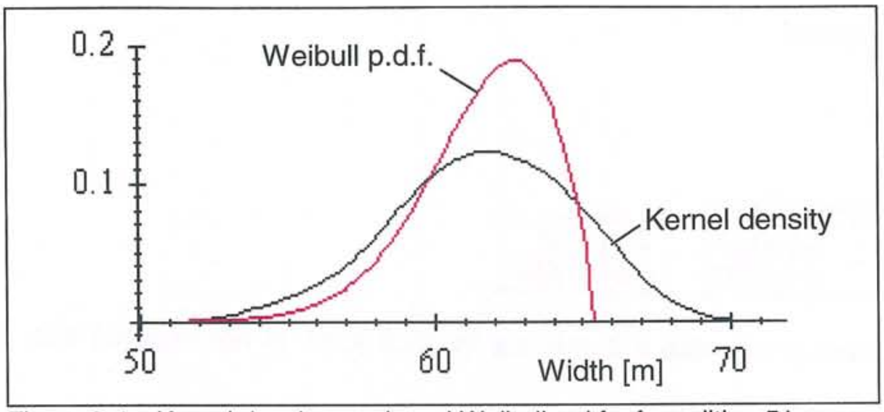

Figure 8-4.c Kernel density graph and Weibull p.d.f. of condition 51

Kolmogorov-Smirnov test

An other criteria is the goodness of fit in the region of the extreme values. This can be checked by using the Kolmogorov-Smirnov test, it compares an empirical distribution function with the distribution function of the hypothesised function. The test statistic is the maximum deviation of one data point (x_i,y_i) in relation to the chosen probability distribution function (see figure 8-5).

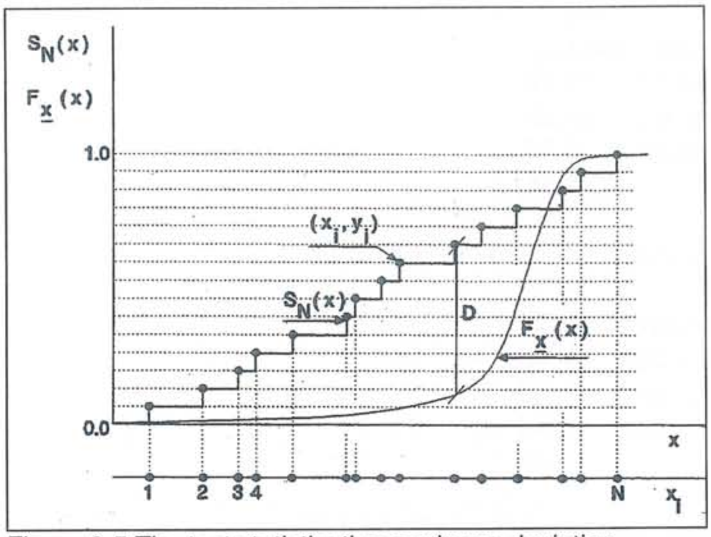

Figure 8-5 The test statistic: the maximum deviation

The method of Bernard / Bos - Levenbach is applied to determine the plot position y_i.

$$y_i = \frac{i-0.3}{N+0.4} \tag{39}$$

where i = 1,2,...,N
N is the number of observations

$$D = \max_{i=1}^{N}\left|S_N(x) - F_x(x)\right| = \max_{i=1}^{N}\left|y_i - F_x(x_i)\right| \tag{40}$$

where $F_x(x_i) = G_\gamma(x_i)$

The hypothesis will not be rejected if the test statistic (D) fulfils the following test;

$$D < \frac{\alpha}{\sqrt{N}} \tag{41}$$

where α is the reliability threshold

α=1.23	10%
α=1.36	5%
α=1.63	1%

Table 8-3 Test statistic D for the conditions

	Cond_26	Cond_44	Cond_51
D	0.12922	0.106702	0.0741488

The conclusion can be drawn from table 8-3 that the Weibull p.d.f. is not rejected with a reliability threshold of 1%.

8.3.3 Fast time versus real time output

In this paragraph the fast time output data is compared with the real time output. In table 8-4 the mean of the parameters max_p, min_s, swept path and max_{max} of the real time simulation and the value of the fast time runs are given. As already stated in paragraph 7.4 condition 51 is the less difficult condition and condition 44 is the most difficult condition of the three conditions that are considered.

Table 8-4.a Average of maximum excursions fast- and real time for cond_26

		E	F	G	H
		max_p	min_s	swept path	max_{max}
A	Fast time	50.18	45.60	95.77	50.18
B	Real time	56.29	49.71	106.00	58.25
C	B-A	6.12	4.11	10.22	8.08
D	B/A				1.16

Table 8-4.b Average of maximum excursions fast- and real time for cond_44

		E	F	G	H
		max_p	min_s	swept path	max_{max}
A	Fast time	56.03	48.67	104.70	56.03
B	Real time	58.45	55.49	113.94	63.62
C	B-A	2.42	6.82	9.24	7.59
D	B/A				1.14

Table 8-4.c Average of maximum excursions fast- and real time for cond_51

		E	F	G	H
		max_p	min_s	swept path	max_{max}
A	Fast time	50.94	47.37	98.31	50.94
B	Real time	48.74	61.62	110.36	61.62
C	B-A	-2.20	14.25	12.05	10.68
D	B/A				1.21

The cell (C,G) gives the absolute difference between the values of the swept path of the real and fast time run. It can be seen from these values that the more difficult the condition is the less the absolute difference between the values of the swept path are.

The cell (D,H) is used here to try to connect the max_{max} data of the real time run with the fast time run. The mean value of the max_{max} value of the real time run divided by the one of the fast time run is on average 1.17. This factor will be used in paragraph 9.2.4.

9. Channel width

9.1 Deterministic design of the width

9.1.1 General

The calculations are performed according to the PIANC [ref. 1] guidelines. The width of the channel is expressed as a multiple of the beam of the design vessel (see Chapter 2). The width of the inner channel is determined using the same guidelines of PIANC. Obviously width additions for current and waves do not apply, because these are eliminated by the breakwaters. Upon entering the harbour the drift angle has a tendency to increase because the bow of the ship is moving out of the current and the moment on the ship increases. Subsequently immediately behind the breakwaters additional space is required. An experienced captain or pilot will anticipate this movement by giving some rudder in opposite direction. In practice allowance is made for this aspect by extending the outside channel width for 2-3 L_s inside the breakwater before narrowing to the inside width (figure 9-1).

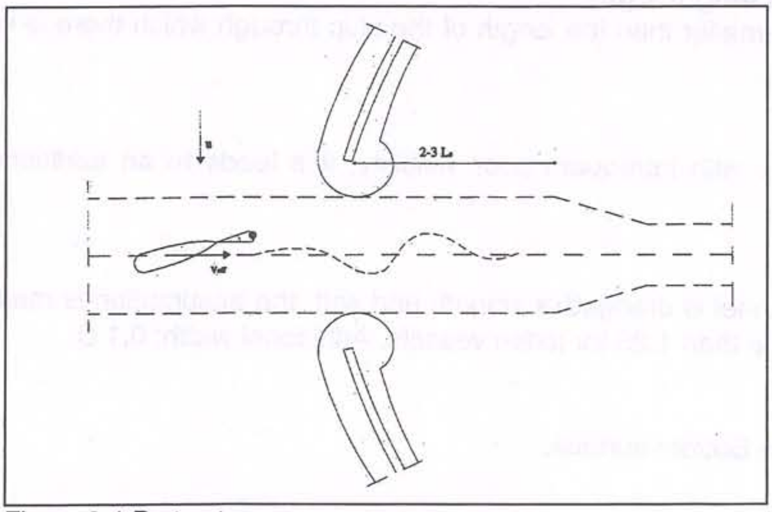

Figure 9-1 Port entrance manoeuvre

where L_s is the length of the vessel

9.1.2 Design

In paragraph 2.2 the deterministic design method is described, in this paragraph the method is used to come up with a width of the channel for the 175,000 dwt bulk carrier. The total required width of the channel is presented in table 9-1.

The bottom width w of the waterway for a one-way channel is given by:

$$w = w_{BM} + \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} \qquad (42)$$

Basic manoeuvring width

The basic manoeuvring width (W_{BM}) is that required by the design vessel to sail safely in very favourable environmental and operational conditions. The ship's manoeuvrability is assumed to be moderate which results in a basic manoeuvring width (W_{BM}) of 1.5·B.

Vessel speed
A speed of 5 to 8 knots (2.5 to 4 m/s) is chosen, which was deducted from previous research to the IJgeul. This leads to no extra allowance.

Prevailing cross wind
The maximum prevailing cross wind is 48 knots (9 Beaufort). Fully loaded vessels are not sensitive to wind, as a result no additional width will be applied for the bulk carrier.

Prevailing cross current
The cross current in the IJgeul is on average 0.5 to 1.5 knots (0.25 to 0.75 m/s). Due to the breaking of waves a strong current of 1.5 to 3 knots (0.75 to 1.5 m/s) can be found in the near shore zone. This results in an additional width of 1.3·B.

Prevailing longitudinal current
The longitudinal current is presumed to vary between 1.5 and 3 knots (0.75 to 1.5 m/s). Subsequently the additional width is 0.2·B.

Significant wave height H_s and length λ (m)
The wave length is in all cases smaller than the length of the ship through which there is no extra allowance for the width.

Aids to navigation
Aids to navigation are moderate with infrequent poor visibility, this leads to an additional width of 0.2·B.

Bottom surface
The plain through which the channel is dredged is smooth and soft, the assumption is made that the depth/draught ratio is less than 1.25 for laden vessels. Additional width: 0.1·B.

Depth of waterway
The extra allowance is 0.2·B, see Bottom surface.

Cargo hazard level
As bulk constitutes a low level of hazard, it is apparent that no extra allowance is required.

Bank clearance
An extra allowance on both sides of the channel is needed of 0.3·B.

Table 9-1 Required width of the channel

Width W_i	Channel exposed to open water
Basic manoeuvring width	1.5·B
Vessel speed	0·B
Prevailing cross wind	0·B
Prevailing cross current	1.3·B
Prevailing longitudinal current	0.2·B
Significant wave height H_s and length λ (m)	0·B
Aids to navigation	0.2·B
Bottom surface	0.1·B
Depth of waterway	0.2·B
Cargo hazard level	0·B
Bank clearance	2·0.3·B
Total	4.1·B

The width of the 175,000 dwt bulk carrier is 48.3 m, subsequently the total required width of the fairway becomes $4.1 \cdot B \approx 198$ m.

9.2 Probabilistic design of the width

9.2.1 General

The channel width will be approximated on the basis of the parameter values of the GEV (see table 8-2). The following remarks should however be made:

- Only the probability of grounding is taken into account in this research (see Chapter 3).
- All simulations were carried out by an inexperienced pilot (me), therefore the output of the real time simulation runs can differ from runs performed by experienced pilots.
- All real time runs were executed in relatively rough conditions.

9.2.2 Width based on safety criteria

As already stated in paragraph 3.2.4 the following equation can be used to determine the acceptable probability of stranding per ship per stretch.

$$p_{acc|ship,stretch} = \frac{p_{str}}{N_{year} \cdot N_{ships} \cdot N_{stretch}} = \frac{0.5}{50 \cdot 200 \cdot 1} = 5 \cdot 10^{-5} \qquad (43)$$

- p_{str} is set at 0.5 [ref. 16], this is the limiting probability of exceedance of lane width of the port side- and starboard bank during the lifetime of the channel for all transits, see also paragraph 4.3.4.
- N_{year} is set at 50 years, this is the normal service time of a channel.
- N_{ships} is set at 200, this is the total number of ship transits for the 175,000 dwt bulk carrier per year.
- $N_{stretch}$ is set at 1, in this research only one maximum value for the deviation of the centre line per run is monitored (max_{max}) therefore the number of independent stretches is set at one.

This results in an acceptable probability of stranding per ship per channel navigation for as well port side as starboard of $2.5 \cdot 10^{-5}$ (see also figure 9-2).

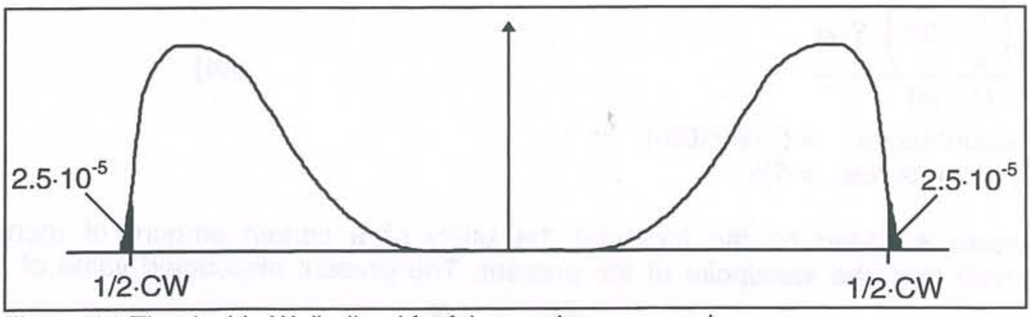

Figure 9-2 The double Weibull p.d.f. of the maximum excursion max_{max}

The half channel width for the different conditions under this criterion is given in table 9-2.

Table 9-2 The half channel width under the probability of grounding of $2.5 \cdot 10^{-5}$ (set I.2a)

	Cond_26	Cond_44	Cond_51
½·CW [m]	73.75	93.68	65.40

The half channel width of condition 51 seems a bit low, see also figure 8-4.c.

9.2.3 Economic optimal width

The theory of an economic optimal design width has already been discussed in paragraph 4.3.4. First the consequence S is expressed in monetary terms (see eq. 13), furthermore also the variable cost of widening the channel is determined (I'). The initial fixed cost (I_0) is of no importance for the economic optimal channel width and will therefore not be estimated.

Consequence (S)
When a ship exceeds the horizontal boundaries of a channel the ship runs aground. There are two different kinds of stranding of a ship. One is a 'normal' stranding, the loss (costs) of the stranding comprise of;

- cost salvage operations
- cost inspection/ repair in a dock
- cost of the ship's delay

A 'severe' stranding takes also into account the loss of human lives, loss of properties and the impact of pollution. Further on the loss when a ship runs aground is defined as average costs, one has to keep in mind that it is a very rough estimation.

Totally 100,000 HP are required to pull the stranded 175,000 dwt bulk carrier. This results in US$ 75,000 per day as the average costs of a tug boat is US$ 0.75 per HP per day. The inspection and repair costs in a dock for such a bulk carrier are estimated at US$ 100,000 per day. The costs of delay per day of the ship are considered to be US$ 50,000.

A duration of an average stranding is estimated here at 15 days, of which the ship is 10 days in the dock for inspection and repair works. This results in a total stranding cost of US$ 2,125,000 for the bulk carrier.

Variable costs (I')
The length of the IJgeul is approximately 23 km. It is assumed that on average 3 m has to be dredged per extra m width. The variable dredging costs are about US$ 2 per m^3. This results in a total cost of US$ 138,000. The real interest rate is set at 4%, so the construction of the channel cost US$ 5,520 per meter width.

Optimal half channel width
Equation (13) can also be written as

$$M_{risk} = \frac{1 - G_\gamma\left(\frac{1}{2}\cdot CW\right)\cdot S\cdot\alpha}{(1-\alpha)} \qquad (44)$$

where α = discount factor $= (1+(r'/100))^{-1}$
r' = real interest rate = 4%

Discounting costs is based on the fact that the utility of a certain amount of money decreases in time from the standpoint of the present. The present discounted value of an amount c in year n is equal to $\alpha^n \cdot c$. Note that $\sum_{i=1}^{\infty}\alpha^i = \frac{\alpha}{1-\alpha}$ if we start counting from year 1 (for $0 < \alpha < 1$).

If the equations (13) and (14) are put together one obtains the total construction cost function (eq. 15). This objective function has to be minimised over the design variable (½·CW) in order to find the optimal design width.

Subsequently 100 fast time runs have been performed for each collection of natural conditions. For each of these runs the max_{max} values are monitored. In Appendix XIV the generated natural conditions and their output is given. The max_{max} data points of the fast time runs have been multiplied by 1.17 to incorporate some sort of human influence, see also paragraph 8.3.3. Finally the GEV p.d.f. has been fitted through both the data sets by using the statistical program Xtremes. The parameter values of the GEV's are given in table 9-4.

Table 9-4 Parameter values of the GEV's

	Set I	Set I & II
γ	-0.180049	-0.01224
μ	47.791	48.2084
σ	8.97932	8.85861
right endpoint	97.6624	772.14

As can be concluded from table 9-4, all the GEV p.d.f. are of the Weibull type as $\gamma < 0$. In table 9-5 the half channel widths based on the safety criterion (see paragraph 9.2.2) and the economic optimal channel widths are given.

Table 9-5 The half channel width

	Set I	Set I & II
Safety criterion	90.26 m	136.25 m
Economic optimal width	75.8 m	81.1 m

$$\frac{\partial C_{tot}}{\partial\left(\frac{1}{2}\cdot CW\right)}=\frac{\partial I'}{\partial\left(\frac{1}{2}\cdot CW\right)}+\frac{\partial M_{risk}}{\partial\left(\frac{1}{2}\cdot CW\right)}=0 \tag{45}$$

$$I'=S\cdot\frac{\partial G_{\gamma}\left(\frac{1}{2}\cdot CW\right)}{\partial\left(\frac{1}{2}\cdot CW\right)} \tag{46}$$

where

$$\frac{\partial G_{\gamma}(x)}{\partial x}=\exp\left(-\left(1+\gamma\cdot\left(\frac{x-\mu}{\sigma}\right)\right)^{-\frac{1}{\gamma}}\right)\cdot\left(1+\gamma\cdot\left(\frac{x-\mu}{\sigma}\right)\right)^{-\left(1+\frac{1}{\gamma}\right)}\cdot\frac{1}{\sigma} \tag{47}$$

In table 9-3 the optimal economic width for the three different conditions are given, which follows from equation (47).

Table 9-3 Economic optimal half channel width (set I.2a)

	Cond_26	Cond_44	Cond_51
½·CW [m]	69.45	80.37	65.40

9.2.4 Required width for average weather conditions

The paragraphs 9.2.2 and 9.2.3 give a half channel width for three different natural conditions. In order to come up with a probabilistic design of the channel width also the frequencies of the natural conditions have to be taken into account. Subsequently not only the extreme conditions should be monitored, instead the generated natural conditions have to represent the weather for a long period of time.

Here it is assumed that a total of 100 natural conditions is sufficient for a good representation of a weather chart. The natural conditions have been generated using the four Matlab programs described in paragraph 6.3.2 and given in Appendix XV.2.

The foregoing has been performed for two collections of natural conditions (see figure 9-3):

- Set I; the maximum current velocity (C_v, velocity just before the harbour entrance) is smaller than 0.6 m/sec and the required water level (WL) is larger than MSL +0.05 m
- Set I & II; overall set of natural conditions

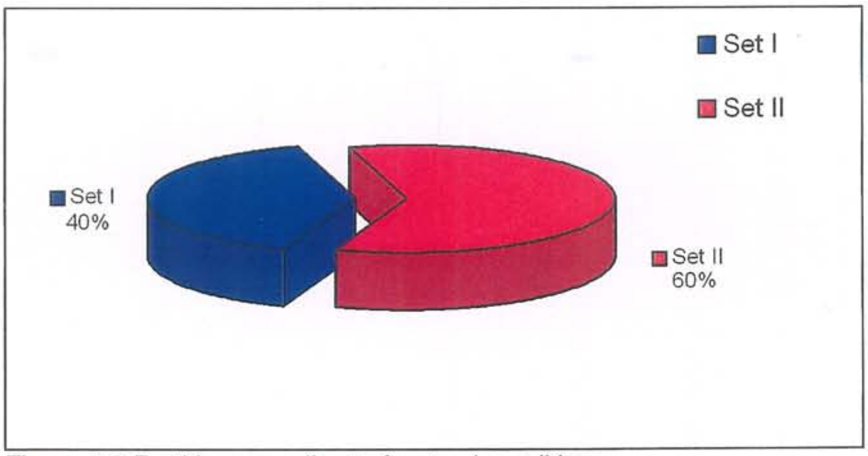

Figure 9-3 Partition overall set of natural conditions

10. Conclusions and recommendations

10.1 Introduction

In the previous Chapters the width of the IJgeul for a 175,000 dwt bulk carrier has been determined in several ways:

- deterministic approach (PIANC guidelines)
- probabilistic approach: - width based on a safety criterion
  - economic optimal width

In this Chapter the whole process and the outcome of the results are evaluated. Also recommendations are made to further research in the subject.

10.2 Conclusions

1. *Operational limit for safe channel navigation of a 175,000 dwt bulk carrier: current velocity before the harbour entrance has to be smaller than 0.6 m/sec.*

   Before a start was made with the selection of natural conditions (see paragraph 6.3.3) a number of fast time test runs have been performed. In these test runs the influence of the wind, currents, seas and swell on the design vessel have been analysed.

   Expectations are that the ship is merely influenced by the current conditions and for a minor part by the wind, as the draught (maximum distance in meters between the waterline and the keel of the ship) of a bulk-carrier is large with respect to the stationary freeboard. The design vessel is not influenced by seas (wind waves) as $L_s > L_0$. The swell waves have little affect to the swept path of the bulk carrier as could be concluded from the test runs.

   Finally it was concluded from the fast time test runs that for a safe passage of a 175,000 dwt bulk-carrier, the current velocity just before the harbour entrance has to be smaller than 0.6 m/sec. No additional limit is set to the wind condition.

2. *A channel transit of a 175,000 dwt bulk carrier is possible in 40 % of the time.*

   A channel transit of the carrier is considered unsafe if the current velocity (C_v) is greater than 0.6 m/sec (see also conclusion 1). Furthermore the required water level (WL) for the bulk carrier is larger than MSL +0.05 m. This resulted in the following selection criteria for a possible transit;

   - $C_v < 0.6$ m/sec
   - WL > MSL +0.05 m

   In total 1,000 natural conditions have been generated randomly, of which approximately 400 conditions complied to the selection criteria.

3. *The maximum excursion of the centre line during a channel navigation run takes place just behind the head of the South breakwater.*

   During the fast time and real time simulation runs the maximum deviation of the ship was monitored visually. This maximum deviation takes place when the bow of the ship passes the head of the South breakwater. Upon entering the drift angle has a tendency to increase because the bow of the ship is moving out of the current and the moment on the ship increases. This is referred to as the 'schieuw' by the pilots of Loodswezen IJmuiden.

To counteract the movement the pilot or captain gives some rudder in opposite direction and possibly a power burst. These control actions can be derived of the output plots of the simulation runs (see figure 7-1).

4. *The distance with a rudder angle greater than twenty degrees is smaller for all real time runs than during the fast time run of the same condition.*

   In Appendix X the data of the performance factors are given, it can be seen that for all three conditions the distance with a rudder angle greater than twenty degrees is smaller for all real time runs than during the fast time run.

5. *The mean value of the widths of the swept path for the real time runs are greater than for the fast time runs.*

   In table 8-4 the widths of the swept path are given for the various conditions. It can be seen that the mean value of the widths of the swept path for the real time runs are greater than for the fast time runs for all conditions.

   The above can be attributed to the following headings:
   - The real time runs were performed by an inexperienced pilot (me) where perhaps an experienced pilot is more capable of keeping to the vessel's intended track. Possibly if a rudder angle of more than twenty degrees is maintained for the same distance as during the fast time run, the widths of the swept path of both the real- and fast time runs agree more (see also conclusion 3).
   - The auto-pilot does not simulate the control capability of a pilot well, the predetermined settings of the auto-pilot have to be adjusted. For instance the anticipation distance can be decreased.

6. *The more difficult the natural conditions are the less the absolute difference between the values of the width of the swept path are.*

   It is striking that the more difficult the natural conditions are the less the absolute difference between the values of the width of the swept path are. This effect can possibly be attributed to the level of attention of the pilot. During a less difficult run his level of attention decreases.

7. *The mean value of the max_{max} value of the real time run divided by the max_{max} value of the fast time run is on average 1.17.*

   If one assumes symmetry around the centre line of the channel the maximum absolute excursion at every position is decisive for the required width. As a result $\max_{\max} = MAX\left(\left|\max_p\right|, \left|\min_s\right|\right)$. In paragraph 8.3.3 the max_{max} values of the real- and fast time runs have been analysed to be able to come up with a connection between the variables. The value $\frac{\max_{\max}(fast)}{\max_{\max}(real)}$ is assumed to be a constant with an average of 1.17 for all three conditions. It has to be noted that this relation is only valid for the runs performed with the NAVSIM simulator for a 175,000 dwt bulk carrier in the IJgeul. There is no overall relation between fast time and real time runs for different simulator programs or different entrance channels.

8. *The distribution function fitted through the max_{max} data points is of the Weibull type.*

The max_{max} data points of the three conditions and of the two sets of 100 fast time runs have been fitted with a Generalised Extreme Value distribution function. This has been done by using the extreme value analysis program Xtremes. For all data series a Weibull p.d.f. was found, this is in accordance with the findings of Prof. Vrijling [ref. 2] and Iribarren [ref. 18].

9. *The calculated acceptable probability of stranding per ship per stretch is $5 \cdot 10^{-5}$ which agrees fairly well with an observed probability of grounding of $3 \cdot 10^{-5}$ per ship movement for Northern European ports [ref. 1].*

The acceptable rate for grounding has been determined by PIANC. This has been done by interrogating large accident databases for Northern European ports. The result shows a remarkably consistent grounding rate of 0.03 accidents per 1,000 ship movements.

This expectation of grounding was consistent throughout the data and, as this was the general rate applying, the inference can be drawn that this level is acceptable to port and ship operators [ref. 1].

10. *The probabilistic design of the width of the IJgeul for a 175,000 dwt bulk carrier is 272.50 m.*

If one accepts no down time for the channel transit of a 175,000 dwt bulk carrier (the transit is possible at every time) and an acceptable probability of stranding per ship per channel navigation for as well port side as starboard of $2.5 \cdot 10^{-5}$ is applied, the channel width for a 175,000 dwt bulk carrier is 272.50 m (see table 9-5). The width is determined using random conditions which represent the weather pattern for a long period of time (weather set I & II).

11. *The widths based on the safety criterion are greater than the calculated economic optimal widths.*

The calculated widths based on the safety criterion for the three conditions and of the two sets of 100 fast time runs are all greater than the same economic optimal width. This can be attributed to the following headings:
- The safety criterion is too narrow, possibly a greater probability of stranding should be used in the risk analysis of the max_{max} data points.
- The consequence (S) is estimated too high and/or the variable cost of widening the channel (I') is estimated too low.

12. *The variables max_p and min_s are independent.*

In Reference 2 (see also Appendix II) it is noted that the variables max_p and min_s are dependent. Subsequently plots for the conditions 26, 44 and 51 have been made of the real time run data of max_p versus min_s (see Appendix XIII). Where max_p is the maximum excursion of the ship on port side during a run and min_s is the maximum excursion of the ship on starboard during a run. No dependency could be deducted from the graphs.

13. *The mean of the drift angle is unequal to zero.*

In Reference 2 (see also Appendix II) the mean of the drift angle is assumed to be zero. In this research it has been concluded from the output data (see Appendix XI) that the mean is unequal to zero. This can be elucidated by figure 10-1.

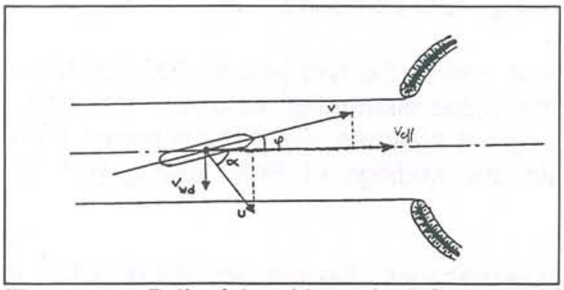

Figure 10-1 Drift of the ship under influence of current and wind

The ship has to maintain an angle with the channel axis in order to counteract the forces due to current and wind. Subsequently the ship sails through the channel with an almost constant drift angle, once the ship's bow passes the harbour entrance the drift angle changes. The mean of the drift angle is zero if the wind- and current forces neutralise each other, this is seldom the case.

10.3 Recommendations

1. *Implementation of the fuzzy set navigator model in a fast time simulation program.*

In order to be able to analyse the resulting statistics of various runs, one has to use a real time simulator or a fast time simulation program with a pilot control model. This model is used instead of the auto-pilot. Papenhuijzen [ref. 11] developed two human operator models. From these two the fuzzy set navigator model schematises the human influence best as can be seen in Appendix I.

As already stated in paragraph 4.2.1, a fast time simulation program in combination with the fuzzy set navigator model has two major advantages in respect to real time simulation runs.

- A run with this model takes a considerably less amount of time in comparison with a real time run.
- No experienced pilot or captain is required to control the helm, engine and tugs.

As a result the cost of performing simulation runs is low, therefore it is recommended to implement the fuzzy set navigator model in a fast time simulator.

2. *Further research into the dependency of natural conditions as wind, current, waves, swell and water level.*

In this research several assumptions have been made in respect to the dependency of the natural conditions, these assumptions have to be checked whether the application is allowed.

- The relation current velocity during spring tide versus current velocity during neap or average tide is linear.
- The wind influences the current velocities over the whole water depth. In reality only the current velocities in the top layer of the water mass are influenced by the wind.
- The relation current velocity versus wind velocity is quadratic.
- The wind has its maximum influence on the current velocities if its direction is perpendicular to the direction of the entrance channel.
- The influence of the wind does not vary in the nearshore zone.
- The correlation between wind at the time of observation and swell is zero, in reality this is not the case.
- The relation water level during spring tide versus water level during neap or average tide is linear.

3. *It is recommended to use the G.P.S. data of pilots of Loodswezen IJmuiden for the probabilistic design of the width of the IJgeul.*

   The pilots of Loodswezen IJmuiden carry a G.P.S. (Global Positioning System) device when they take over the controls of the ship from the captain. The G.P.S. device saves data of the location of the ship through the whole channel transit.

   A probabilistic design of the channel can be produced by using these data. Notice has to be paid that the pilot tries to keep the ship's track (the centre line of the channel) as much as possible. Afterward the transit the pilot determines the maximum deviation of the ship with respect to the centre line of the channel. This needs to be done for a large number of transits to be able to come up with a reliable probabilistic design of the width of the IJgeul.

   This has not been done in this research as the data of the G.P.S. device are erased after every channel transit, as a result no data are available for statistical analysis.

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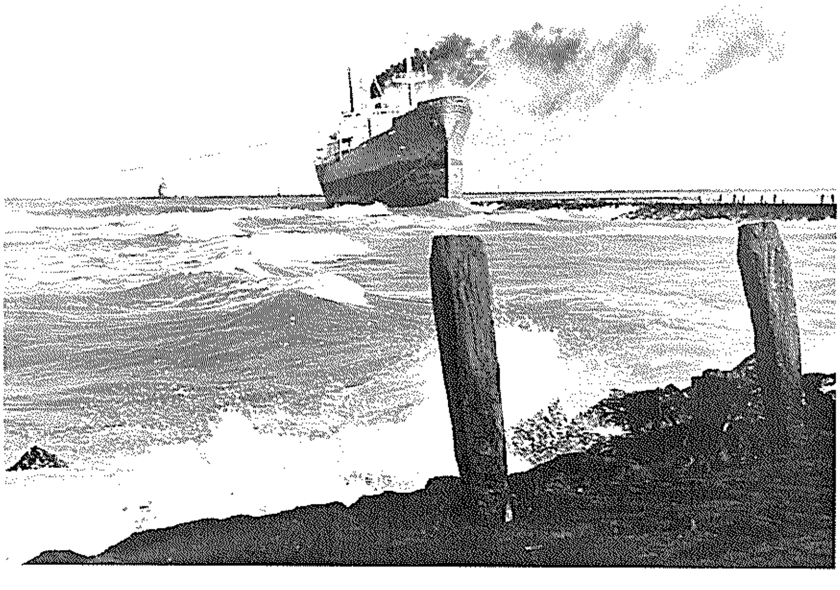
Risk analysis of vessels exceeding horizontal boundaries in a channel

Appendices

Risk analysis of vessels exceeding horizontal boundaries in a channel

Appendices



AVV Transport Research Centre
Section Navigation and Waterways
W. Welvaarts
June 2001

List of Appendices

Appendix I: Human operator of the navigator model

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1. General

The thesis study of R. Papenhuijzen 'Towards a Human Operator Model of the Navigator' investigated the feasibility of a general purpose human operator model of the navigator. This model can be applied in a fast time simulator. The outcome of the study were two models, the control theoretic navigator model and the fuzzy set navigator model. Both these computer models can be inserted in a fast time simulator in order to schematise the human influence on the sailed track.

2. Control theoretic navigator model

The navigator model is primarily meant for research into the navigability of individual fairways. The complete model has been divided into three major components, describing the navigator's state estimating, track planning and track following behaviour, respectively. Below a description is given of the planning and control, or track following, behaviour. First a discrimination is made between so-called Long Term Planning (LTP) and Short Term Planning (STP); a long term planning sub-model determining a desired route and a preliminary time planning, whereas a short term planning model decides on the exact trajectory to follow.

As the on-line simulation process starts, a desired trajectory is constructed on a time interval that is bounded by one of the LTP-subgoals. Subsequently the STP-model accomplishes the plan by applying an optimal control law and minimum cost function. Once the detailed short term plan has been drawn up, the track following process can start. Deviations from the planned trajectory are evaluated, and, if necessary, control actions are taken.

3. Fuzzy set navigator model

The following aspects are of importance in the track planning submodel.

- There is a close interrelation between the two individual problems of planning tracks and defining safety zones. Obviously, the geometry of a curved track element is partially determined by the safety zones.
- The shape of the planned track is dominated by the ship's dimensions and manoeuvrability, or better, by the navigator's perception of these characteristics (figure 1). The upper part of the figure illustrates that an inland vessel captain, given this schematic fairway geometry, is inclined to choose a desired as a series of three lanes and two arcs of circle. This is preferred to navigating the waterway as one large arc of circle. On the other hand, for a sea-going vessel, it will not be possible to realise the large variations in rate of turn that are required by the first manoeuvre. Therefore, in this case, a navigator will plan a track that looks much more like the one in the lower part of the figure.

Supervisory and manual control behaviour is simulated by the track following submodel. From time to time, future states are predicted. The predicted states are evaluated by relating them to the perception of safety as determined by the track planning submodel, and by assessing the measure to which future states diverge from the desired states as defined by the planned track. If necessary, a control action is carried out.

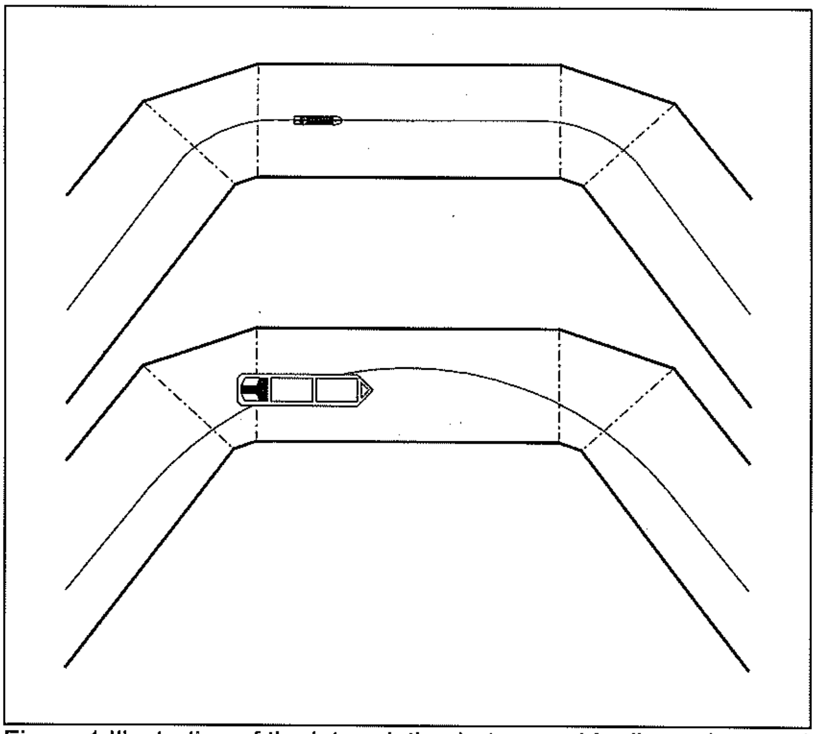


Figure 1 Illustration of the interrelation between ship dimensions and track planning

In table 1 an overview is given of the functional differences of the two models.

Table 1 Overview of the major functional differences between the two navigator models

issue	**control theoretic navigator model**	**fuzzy set navigator model**
performance	• one plan per trial • track planning fairly slow • track following fast	• more trials per plan • track planning slow • track following fairly slow
basic philosophy	normative; realistic overall simulation output, unrealistic navigator model output	descriptive; realistic overall simulation output, realistic navigator model output
track planning strategy	concatenation of lanes and arcs of circle; realistic, adequate for most navigation tasks	any form; sufficiently realistic, adequate for all navigation tasks
engine speed control	inherent in the mechanism; already implemented	difficult to implement
trade-off between risk perception and position estimation error	implemented; only necessary under night vision conditions or when aids to navigation are scarce	could be implemented
time-varying environment definition	inherent in the mechanism; can be implemented simply	could be implemented, but probably not quite satisfactorily
traffic simulation	simple for the floating island concept; conceptually possible for simulating full interaction, but extremely laborious if a large number of ships is involved	difficult for the floating island concept; relatively simple for simulating full interaction, as long as no complex collision avoidance manoeuvres or large deviations from the planned track are needed
other applications	simple implementation of automatic navigation for single ship situations; feasible for traffic handling	simple implementation of automatic navigation for single ship situations; no future as to traffic handling

In order to verify the two models, Papenhuijzen performed two case studies. For every experiment trials were performed by a harbour pilot on the ship bridge simulator and trials were performed by the control theoretic and fuzzy logic control model. In figures 2 to 7 the outcome of the case study 'Mississippi harbour' is given.

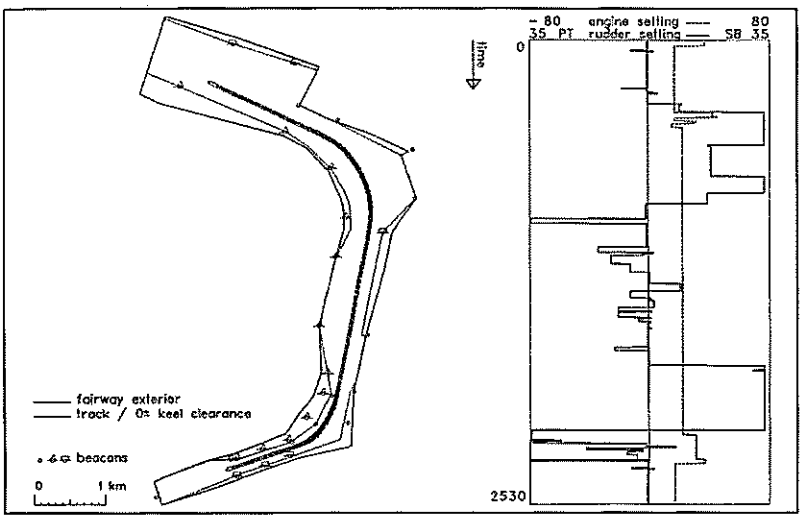


Figure 2

One of the trials of experiment miss_b_0 (Mississippi harbour; bulk carrier; moderate wind), performed by a harbour pilot on the ship bridge simulator

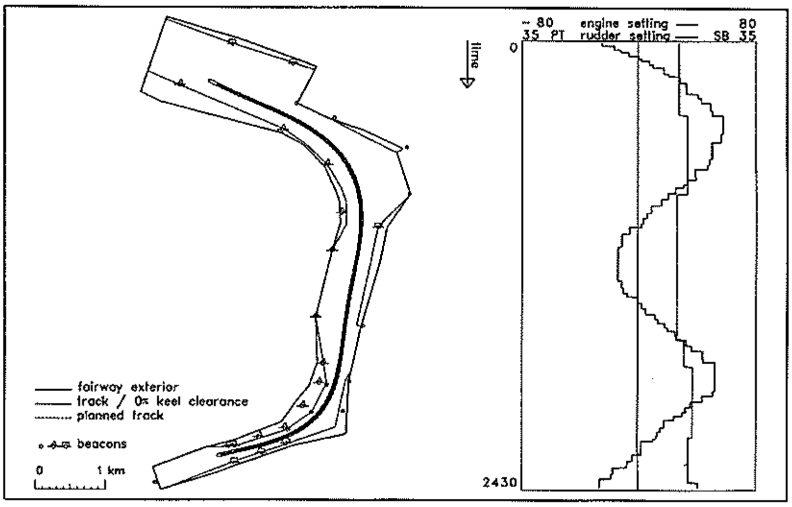


Figure 3

One of the trials of experiment miss_b_0 (Mississippi harbour; bulk carrier; moderate wind), performed with the control theoretic navigator model

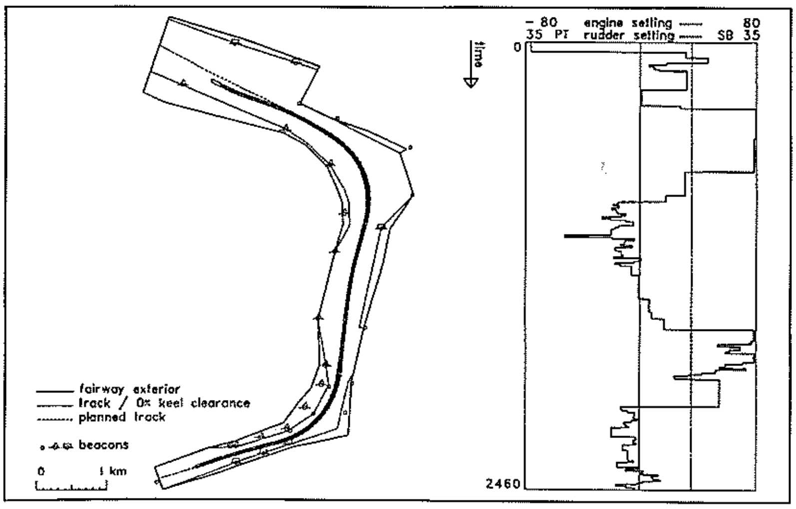
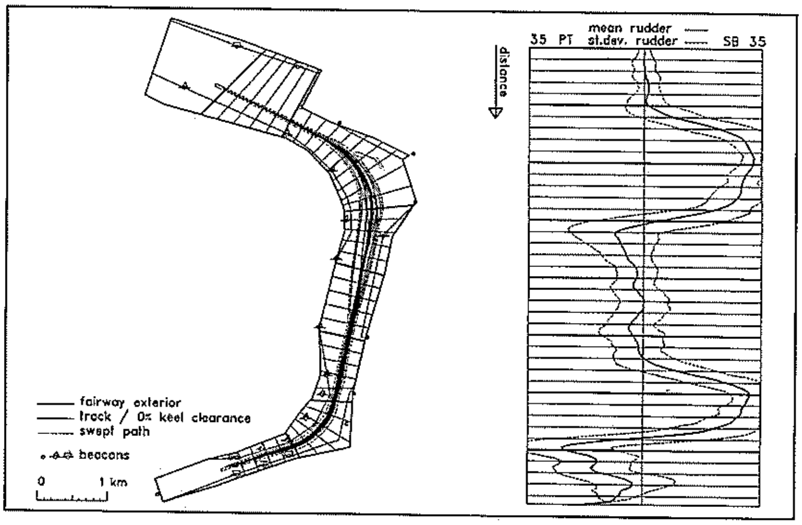


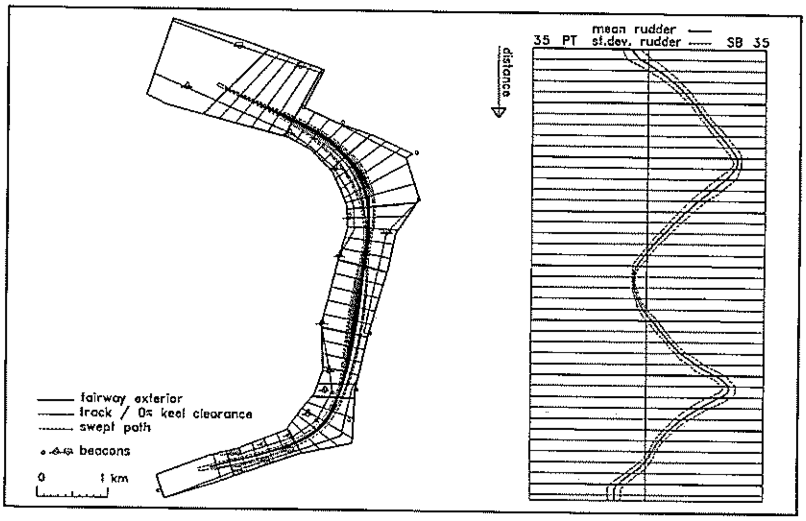
Figure 4

One of the trials of experiment miss_b_0 (Mississippi harbour; bulk carrier; moderate wind), performed with the fuzzy set navigator model



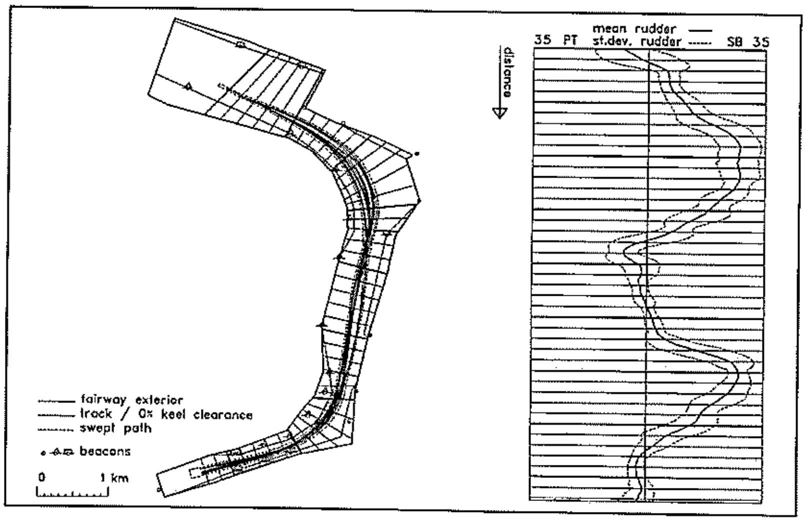
Analysis of all trials of experiment miss_b_0 (Mississippi harbour; bulk carrier; moderate wind) which was performed by harbour pilots on the ship bridge simulator

Figure 5



Analysis of all trials of experiment miss_b_0 (Mississippi harbour; bulk carrier; moderate wind) which was performed with the control theoretic navigator model

Figure 6



Analysis of all trials of experiment miss_b_0 (Mississippi harbour; bulk carrier; moderate wind) which was performed with the fuzzy set navigator model

Figure 7

Appendix II: Existing probabilistic design methods

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1. PRODIM [ref. 3]

The CVB (Commissie Vaarwegbeheerders) drafts guidelines for the design of fairways. For the smaller fairways (CEMT-class 0 to 4) one uses the deterministic design method, for larger fairways the width becomes too large, as a result the need was risen to start a research to the probabilistic analysis of the cross-section of fairways. As a result ORTEC consultants came up with a computer-program, PRODIM, which calculates the dimensions of the cross-section of an inland waterway in a probabilistic way.

1.1 General

In this study a model is made using a channel compartment and on both sides of the compartment vessels are generated. The vessels are subdivided into 11 classes, in which the vessels of one class have the same dimensions. Every vessel is either loaded or unloaded and is sailing downstream or upstream the river, this results in 44 different types. The vessel generator can vary the vessel intensity per type and per hour. The traffic situation in the middle of the compartment is being registered, this list and their probability of occurrence will be coupled with the list of wind-direction and -velocity. For every combination of traffic situation and wind circumstances the required width of the channel is calculated. Using the probabilities of both variables the probability of the necessary channel width can be obtained.

As unloaded vessels have a greater wind area an extra allowance has to be implemented, for loaded vessels an extra allowance for the basic manoeuvring lane (W_{BM}) is applied.

1.2 Starting points

In the study three unsure factors are distinguished:
- traffic intensity
- vessel velocity
- wind circumstances

which are being modelled as independent variables.

Traffic intensity
Vessels are generated at both boundaries of the compartment according to independent Poisson distribution functions.

Vessel velocity
The vessel speed of type i is presumed to follow a normal (cut off) distribution with a mean μ_i and a standard-deviation σ_i. The vessel speed will not be influenced by current or wind.

Wind circumstances
- Starting point is a density function with a probability for every combination of wind-velocity and wind-direction on a height of 10 m above water level, this density function will be referred to as the basic wind circumstance.
- The basic wind circumstance is being disturbed by additive squall, which takes place during 10 minutes every hour. The squalls will be generated by an independent Gaussian distribution function. The sum of the basic wind circumstances and the squalls will be referred to as the total wind.
- The wind velocities will be multiplied by 0.842, in order to obtain the wind velocity at a height of 4 m above water level.

Traffic situations with more than 4 vessels at the same time in the middle area of the compartment are not realistic. With the assumption of 44 types of vessels one can distinguish a total of 194,580 traffic situations.

1.3 Simulation approach

In the simulation the interdependence of the variables is used to reduce the required number of simulations, it is being divided into two different phases. In the first phase the traffic situations in the middle of the compartment are being registered, in the second phase the required width of the channel is being calculated.

The total required width for the vessel to manoeuvre is determined by the drift angle, the width can be calculated by using the following formula:

$$B = B_{vessel} \cdot \cos\beta + L_{vessel} \cdot \sin\beta \qquad (1)$$

The drift angle depends on the draught of the vessel and the wind velocity perpendicular on the vessel. The drift angle for loaded vessels is presumed to be almost zero, for unloaded vessels holds the following formula:

$$\bar{\beta} = 0.447 \cdot \left(V_{wl} / V_s \right)^2 \qquad (2)$$

where $\bar{\beta}$ = average drift angle
V_{wl} = wind velocity perpendicular to the channel axis
V_s = vessel speed

The following linear relation takes the draught of the vessel into account:

$$\beta = 1.125 \cdot \bar{\beta} - 0.6 \cdot \bar{\beta} \cdot \frac{T_v}{T_{max} - T_{min}} \qquad (3)$$

where T_v = draught vessel
T_{max} = maximum draught vessel
T_{min} = minimum draught of vessel

2. Ennore, probability of obstruction of the entrance channel [ref. 2]

In this report the probability of the obstruction of the entrance channel of the Ennore Coal Port is analysed. The study is limited to one failure mechanism, only the stranding of a ship on the shores of the channel due to a navigational error is considered.

2.1 Mathematical model

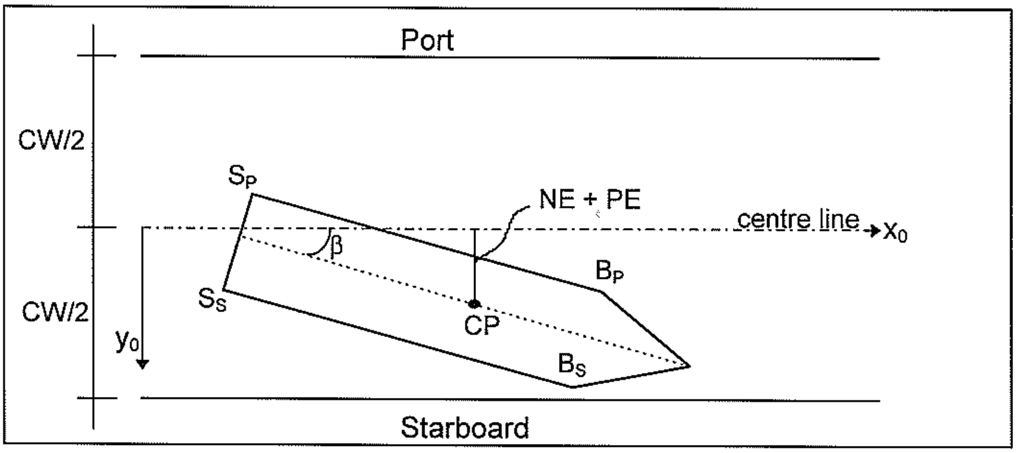

Figure 1 Definition sketch

where CP = central point
NE = navigation error
PE = position error
CW = channel width
β = drift angle

If a vessel progresses in a channel, the positions of the four corners are of interest. When the position of the bow is indicated with B and the stern with S and port and starboard with the subscripts p and s, the following formula define the positions (figure 1):

$$B_s = NE + PE + \frac{L}{2} \cdot \sin\beta + \frac{B}{2} \tag{4a}$$

$$B_p = NE + PE + \frac{L}{2} \cdot \sin\beta - \frac{B}{2} \tag{4b}$$

$$S_s = NE + PE - \frac{L}{2} \cdot \sin\beta + \frac{B}{2} \tag{4c}$$

$$S_p = NE + PE - \frac{L}{2} \cdot \sin\beta - \frac{B}{2} \tag{4d}$$

The positions of the outer port and starboard corners are easily identified as the smallest and the largest values of the four corner co-ordinates:

$$\max_s = NE + PE + \left|\frac{L}{2} \cdot \sin\beta\right| + \frac{B}{2} \tag{5a}$$

$$\min_p = NE + PE - \left|\frac{L}{2} \cdot \sin\beta\right| - \frac{B}{2} \tag{5b}$$

During simulator runs these values are mostly tracked. The area between the lines of max_s and min_p resulting from one simulation is mostly indicated as the swept path. For the design of the width of the channel a further step is required. Assuming symmetry around the centre line of the channel the maximal absolute excursion at every position is decisive for the required width.

$$\max_{\max} = MAX\left(\left|\max_s\right|,\left|\min_p\right|\right) \qquad (6)$$

It can be shown that the expression for this maximal value is defined by:

$$\max_{\max} = \left|NE + PE\right| + \left|\frac{L}{2}\cdot\sin\beta\right| + \frac{B}{2} \qquad (7)$$

The half channel width should be larger than this value to avoid stranding. Symmetry is assumed in this study, although some publications (PIANC) indicate a systematic navigation error due to the influence of wind and current abeam. It is reasoned here that an inexperienced helmsman may drift slightly off the centre line, but that an experienced skipper will anticipate the drift by trying to steer above the centre line. So on average the navigation error has no systematic component and the maximums to port and starboard are equal.

To calculate the probability of stranding the requirement of non-stranding has to be fulfilled for both shores. This leads to the following reliability function that comprises the channel width CW:

$$Z = \frac{CW}{2} - \left|NE + PE\right| - \left|\frac{L}{2}\cdot\sin\beta\right| - \frac{B}{2} < 0 \qquad (8)$$

2.2 Probabilistic evaluation of the model

For all random variables in the mathematical model, normal distribution functions are assumed, the parameter values chosen on the basis of engineering and seafaring experience are given in table 1.

Table 1 Normal distribution data

variable	μ	σ	units
L	245	0	[m]
B	32.2	0	[m]
β	0	0.175	[rad]
NE	0	20	[m]
PE	0	5	[m]

Using the expressions for max_s and min_p the mean and the standard deviation of these variables can be found by applying the error propagation theory (also indicated as mean value first order second moment or Level II approach).

It should be noted that the 'absolute' operator applied on a normally distributed variable x with zero mean leads to a half-normal distribution of y = |x| with a mean equal to $0.8\cdot\sigma_x$ and a standard deviation of $0.6\cdot\sigma_x$. Using this result and applying the error propagation theory the mean and standard deviation of max_s and min_p can be calculated:

$$\mu\left(\max_s\right) = 0 + 0 + 0.8\cdot\frac{245}{2}\cdot\cos(0)\cdot 0.175 + \frac{32.2}{2} = 33.25m \qquad (9)$$

From symmetry it follows that:

$$\mu(\min_p) = 0 + 0 - 0.8 \cdot \frac{245}{2} \cdot \cos(0) \cdot 0.175 - \frac{32.2}{2} = -33.25m \quad (10)$$

The standard deviation can be derived as follows:

$$\sigma(\max_s)^2 = 5^2 + 20^2 + \left(0.6 \cdot \frac{245}{2} \cdot \cos(0) \cdot 0.175\right)^2 = 24.3^2 m^2 \quad (11)$$

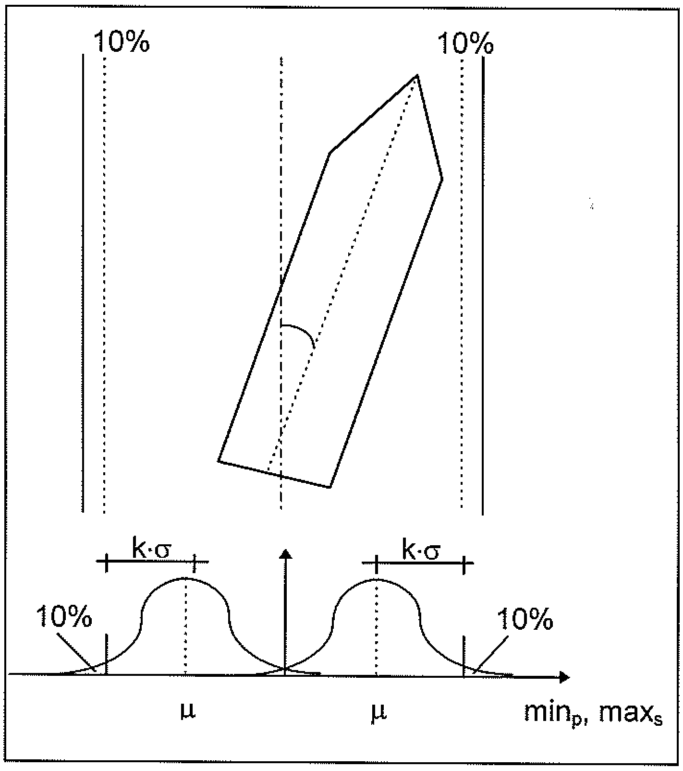

Figure 2 The distributions of the two dependent variables $\min_p$ and $\max_s$

Herewith the distributions of the two dependent variables $\max_s$ and $\min_p$ are approximated, these variables can be approximated more accurately by using the Monte Carlo analysis.

Because of the dependency of the variables $\max_s$ and $\min_p$ the extreme value theory cannot be used to find the maximum absolute excursion in each stretch. The exact expression for this maximum $\max_{max}$ has to be taken. Following the same error propagating procedure the mean, standard deviation and distribution of $\max_{max}$ can be approximated.

$$\mu(\max_{\max}) = 0.8 \cdot \sqrt{\sigma_{NE}^2 + \sigma_{PE}^2} + 0.8 \cdot \frac{245}{2} \cdot \cos(0) \cdot \sigma_\beta + \frac{32.2}{2} = 49.75m \quad (12)$$

$$\sigma(\max_{\max})^2 = 0.6^2 \cdot (\sigma_{NE}^2 + \sigma_{PE}^2) + \left(0.6 \cdot \frac{245}{2} \cdot \cos(0) \cdot \sigma_\beta\right)^2 = 17.8m \quad (13)$$

The p.d.f. is skewed, because it is the sum of two half-normally distributed variables. In this case the distribution appears to be of the Weibull type. The results for various channel widths are shown in table 2.

Table 2 Probability of stranding

CW [m]	$P_{stranding}$
75	$41 \cdot 10^{-2}$
150	$4.5 \cdot 10^{-2}$
200	$0.3 \cdot 10^{-2}$
250	$1.0 \cdot 10^{-4}$

2.3 Verification and calibration of the model with the real time simulations

To judge the safety of the passage of the entrance channel under various circumstances 30 simulator runs have been performed by MSCN. In these runs experienced harbour managers and pilots of Madras Port steered a 60,000 DWT vessel through the channel. The course, the position and a number of nautic data were recorded.

From the recorded tracks of these runs max_s and min_p have been taken. Normal distributions have been fitted through these two sets of 30 data points each. The results are given in table 3.

Table 3 Data recorded tracks

variable	μ	σ	units
max_s	38.3 (33.25)	24.27 (24.3)	[m]
min_p	28.1 (33.25)	24.98 (24.3)	[m]
max_s and $\lvert min_p \rvert$	33.2 (33.25)	24.95 (24.3)	[m]

The values compare very well with the predictions of the probabilistic model, that are given in brackets.

2.4 The acceptable probability of stranding

In a probabilistic approach the width of the channel follows from the choice of the acceptable probability of stranding. To find the acceptable probability of stranding for one stretch of channel and one ship, the number of independent stretches and the number of ships per year have to be taken into account. From an economic point of view, the planning period of the channel has to be considered as well. The length of an independent stretch relates to a half wavelength of the ships track in the channel. The acceptable probability of stranding will now be:

$$p_{acc|ship,stretch} = \frac{p_{str}}{N_{year} \cdot N_{ships} \cdot N_{stretch}} \qquad (14)$$

where p_{str} is the acceptable probability of stranding in the planning period
N_{year} is the duration of the planning period in years
N_{ships} is the number of ships entering the port every year
$N_{stretch}$ is the number of independent stretches

Appendix III: NAVSIM

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1. General

NAVSIM is a ship manoeuvring simulation model developed by Alkyon. The control of the vessel can be handled 'real-time' by using the keyboard and mouse, as well as 'fast-time' in case of which the control of the vessel is handled by a steering device. The main advantage of the 'fast-time' mode is its high speed of calculation, through which a normal run takes only several minutes.

The real-time simulator is not of the full mission type, instead the navigator can observe the actual position of the vessel in its surroundings from a bird's eye view (see figure 1). The instrument panel is projected on a second screen (see figure 2), it contains regulators for engine and rudder control.

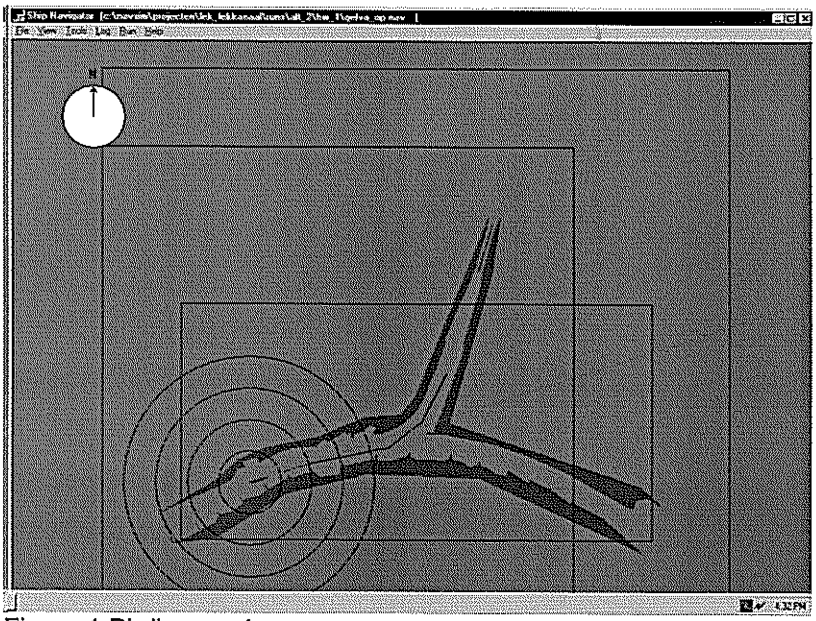

Figure 1 Bird's eye view

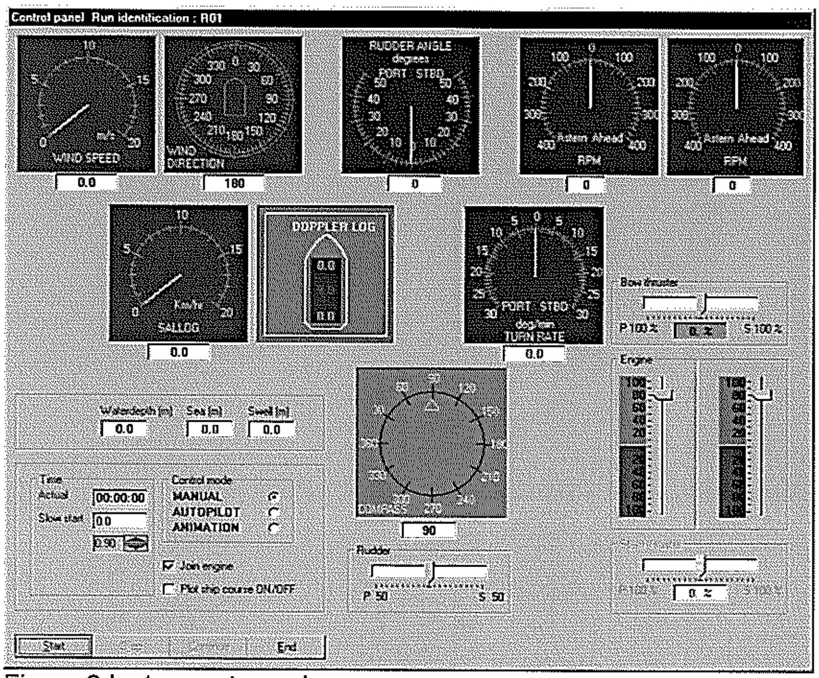

Figure 2 Instrument panel

2. Basic principle of the model

The manoeuvring model is the hart of the program, it describes the forces and moments acting on the vessel due to current, wind, waves and vessel control. Using the second law of Newton ($F = m \cdot a$), the program can calculate the acceleration of the vessel. This calculation is repeated for every time-step.

3. Modules

The program comes in five modules, the main modules are;

- Ship the actual simulation program
- Post-navigator program to analyse the saved navigation runs

The module Ship comprises of several input files, input files describing the lay-out of the channel are;

[Bottom]	Water-depth, the depth is given for all the grid-points
[Polygoon]	Contours of the channel
[Track]	Desired track
[InitShip]	Conditions for the start of the simulation (position, heading, velocity of the ship, rudder angle)

Input files describing the vessel;

[Ship]	Ship's characteristics (length, beam, draught, mass, moment of inertia, wind-surface)
[ShipContour]	Ship's contours for the bird's eye view
[Rudder]	(maximum rudder angle, maximum rate of change of rudder, location rudder)
[Propeller]	(maximum propeller acceleration, data side thrusters)
[Hull]	Manoeuvring coefficients
[WindForce]	Wind force coefficients in relation to the angle of attack
[WaveForce]	Wave force coefficients in relation to the angle of attack

Input files describing the external conditions;

[Current]	Current field (current velocity in the x and y direction)
[Wind]	Wind field (wind velocity in the x and y direction)

Appendix IV: Wind affect on current velocity

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1. General

In this paragraph table 4-1 and 4-2 are used to come up with a connection between the current velocities during northern wind 10 m/sec or south-western wind 14 m/sec on the one hand and the astronomic current velocities on the other hand. The outcome of these results is summarised in table 4-3.

Table 1 Ratio current velocity during northern wind 10 m/sec and astronomic current velocity (flood)

	A	B	
	Astronomic tide	Wind N 10 m/sec	B/A
6-1-1996 15:30-16:00	0.84 m/sec	0.75 m/sec	0.89
7-1-1996 04:00-04:20	0.83 m/sec	0.74 m/sec	0.89
7-1-1996 16:10-16:40	0.88 m/sec	0.79 m/sec	0.90
8-1-1996 04:30-04:50	0.85 m/sec	0.76 m/sec	0.89
8-1-1996 16:40-17:00	0.91 m/sec	0.81 m/sec	0.89
		Average	0.89

Table 2 Ratio current velocity during south-western wind 14 m/sec and astronomic current velocity (flood)

	A	B	
	Astronomic tide	Wind SW 14 m/sec	B/A
6-1-1996 15:30-16:00	0.84 m/sec	1.13 m/sec	1.35
7-1-1996 04:00-04:20	0.83 m/sec	1.10 m/sec	1.33
7-1-1996 16:10-16:40	0.88 m/sec	1.16 m/sec	1.32
8-1-1996 04:30-04:50	0.85 m/sec	1.11 m/sec	1.31
8-1-1996 16:40-17:00	0.91 m/sec	1.18 m/sec	1.30
		Average	1.32

Table 3 Ratio current velocity during northern wind 10 m/sec and astronomic current velocity (ebb)

	A	B	
	Astronomic tide	Wind N 10 m/sec	B/A
6-1-1996 21:40-21:50	-0.82 m/sec	-0.89 m/sec	1.09
7-1-1996 09:50-10:00	-0.84 m/sec	-0.91 m/sec	1.08
7-1-1996 22:10-22:20	-0.84 m/sec	-0.91 m/sec	1.08
8-1-1996 10:20-10:30	-0.85 m/sec	-0.92 m/sec	1.08
8-1-1996 22:10-22:50	-0.84 m/sec	-0.91 m/sec	1.08
		Average	1.08

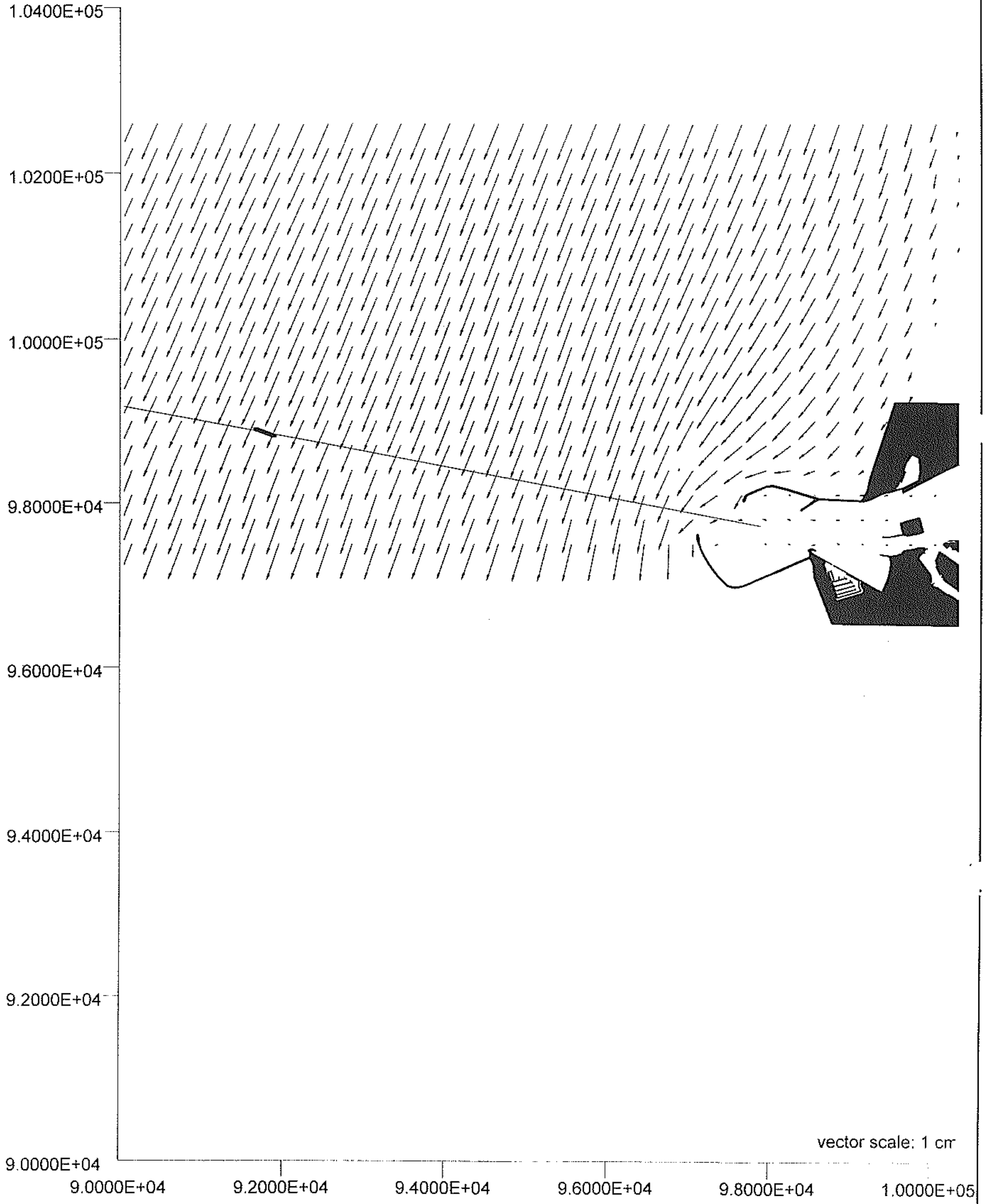
Table 4 Ratio current velocity during south-western wind 14 m/sec and astronomic current velocity (ebb)

	A	B	
	Astronomic tide	Wind SW 14 m/sec	B/A
6-1-1996 21:40-21:50	-0.82 m/sec	-0.50 m/sec	0.61
7-1-1996 09:50-10:00	-0.84 m/sec	-0.50 m/sec	0.60
7-1-1996 22:10-22:20	-0.84 m/sec	-0.53 m/sec	0.63
8-1-1996 10:20-10:30	-0.85 m/sec	-0.54 m/sec	0.64
8-1-1996 22:10-22:50	-0.84 m/sec	-0.55 m/sec	0.65
		Average	0.63

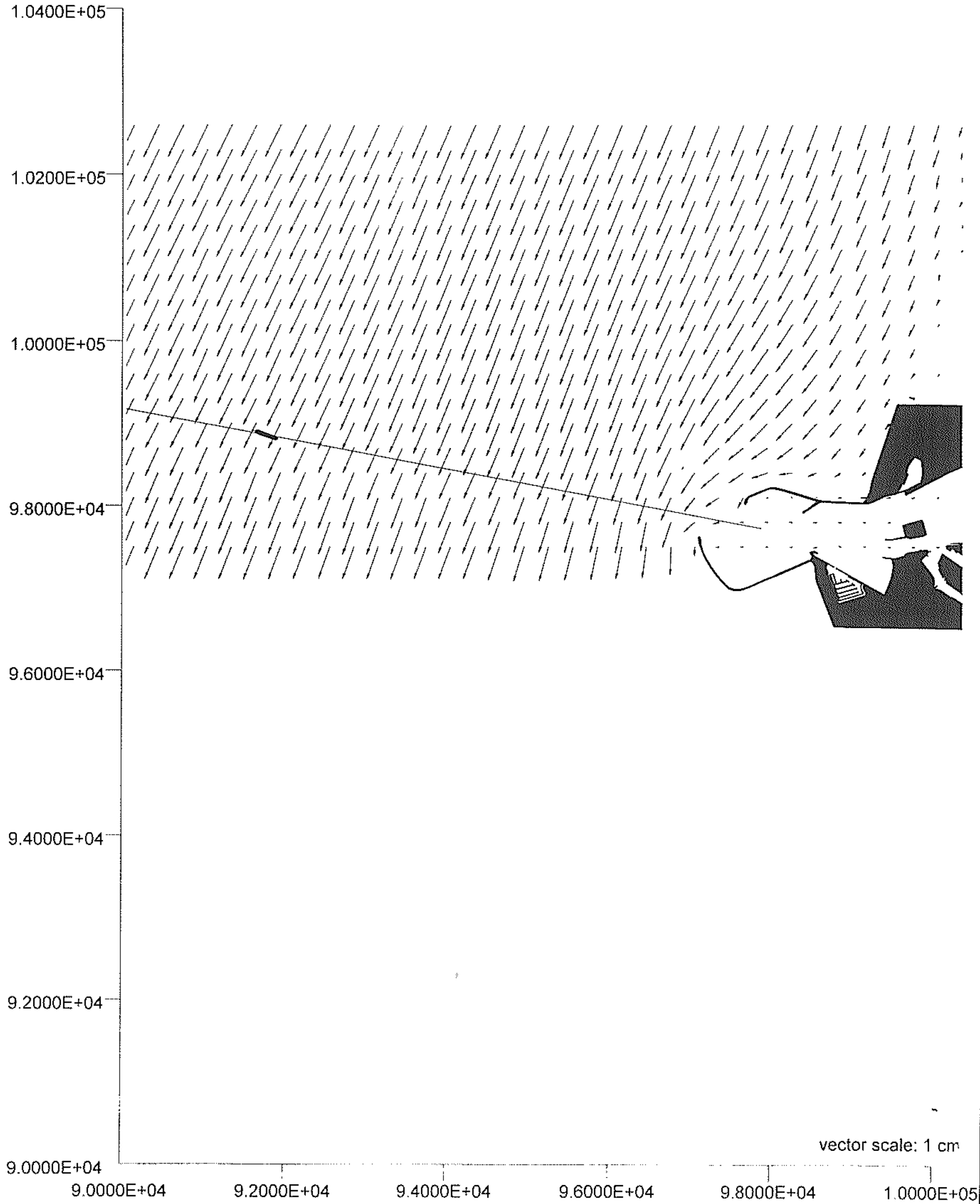
Appendix V: Current pattern near IJmuiden

List of figures:

Alkyon 5/16/01 1 37 44 AM

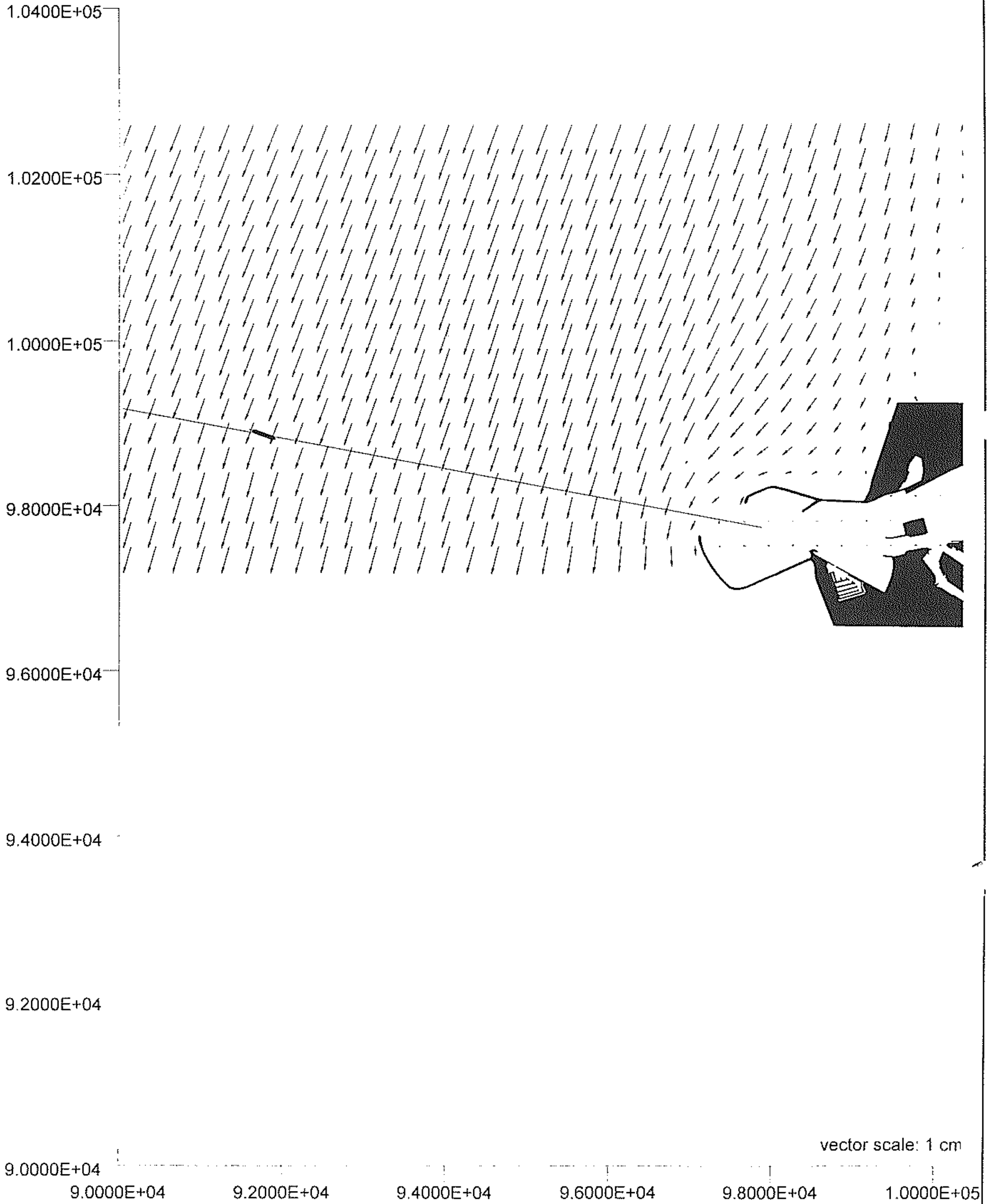


Current pattern near IJmuiden Spring tide, High Water -6 hours	R01	Figure 1
	W. Welvaarts	
AVV Transport Research Centre		

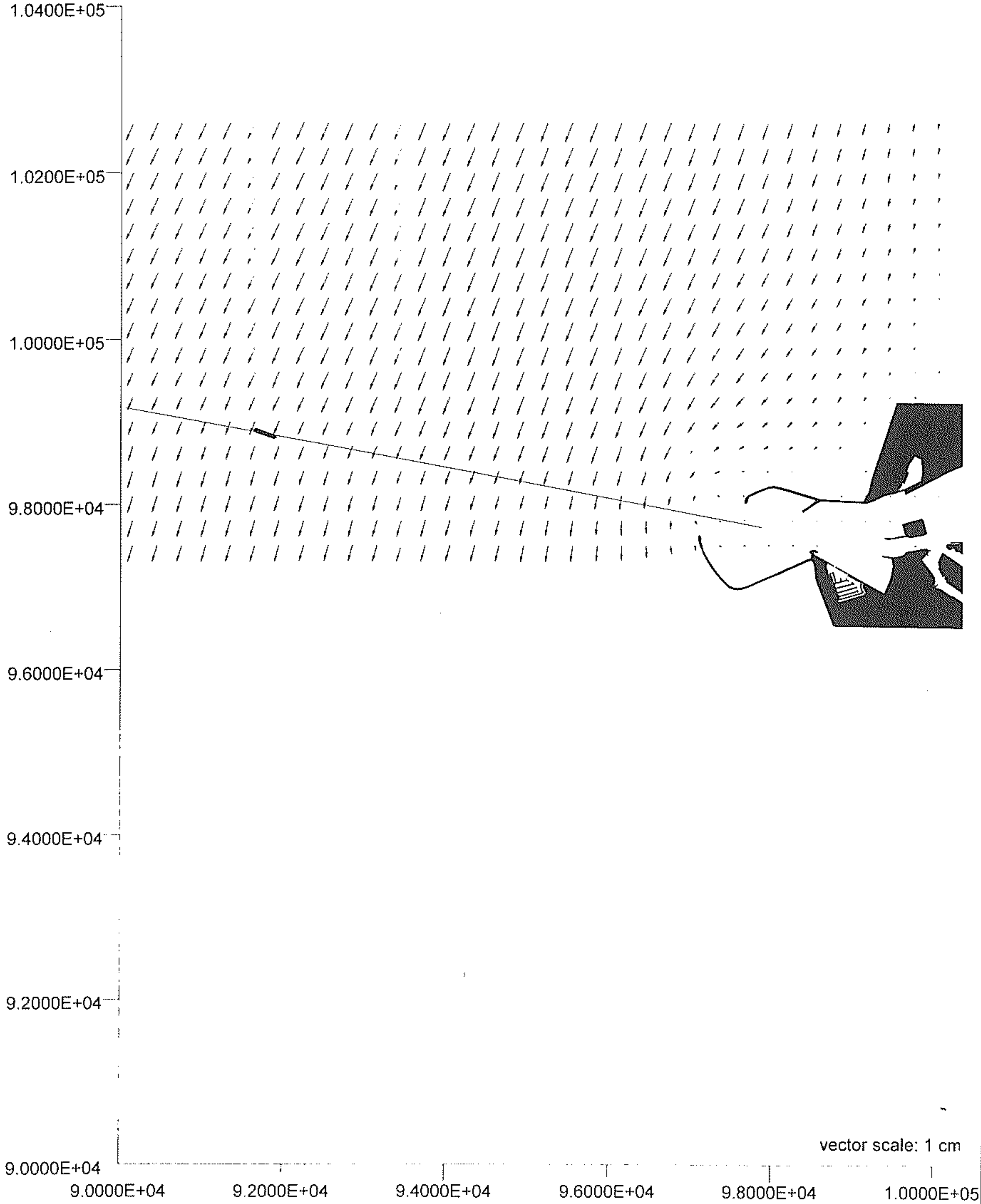


Current pattern near IJmuiden Spring tide, High Water -5 hours	R02	Figure 2
	W. Welvaarts	
AVV Transport Research Centre		

Alkyon 5/16/01 1 50 56 AM

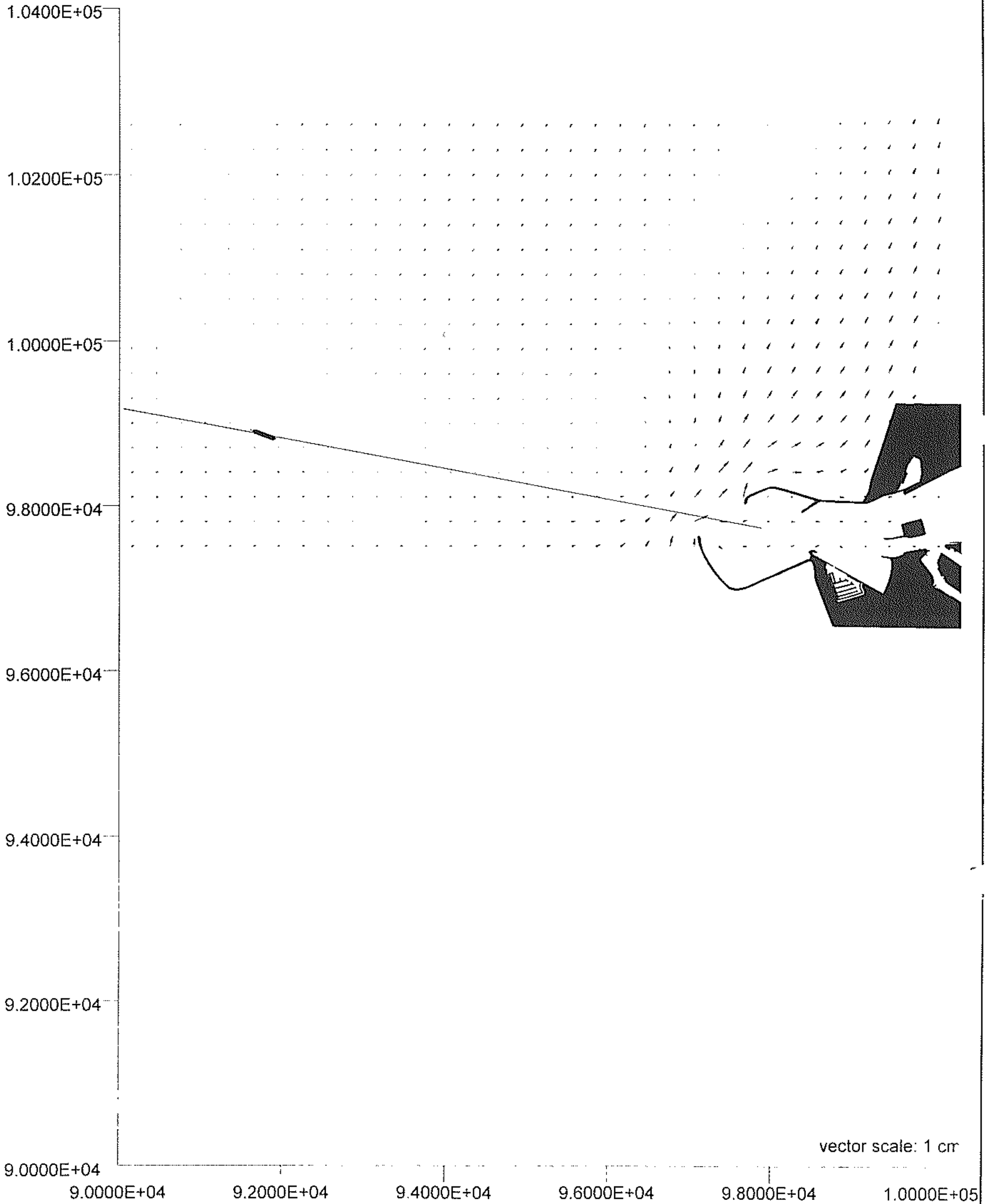


Current pattern near IJmuiden	R03	Figure 3
Spring tide, High Water -4 hours	W. Welvaarts	
AVV Transport Research Centre		



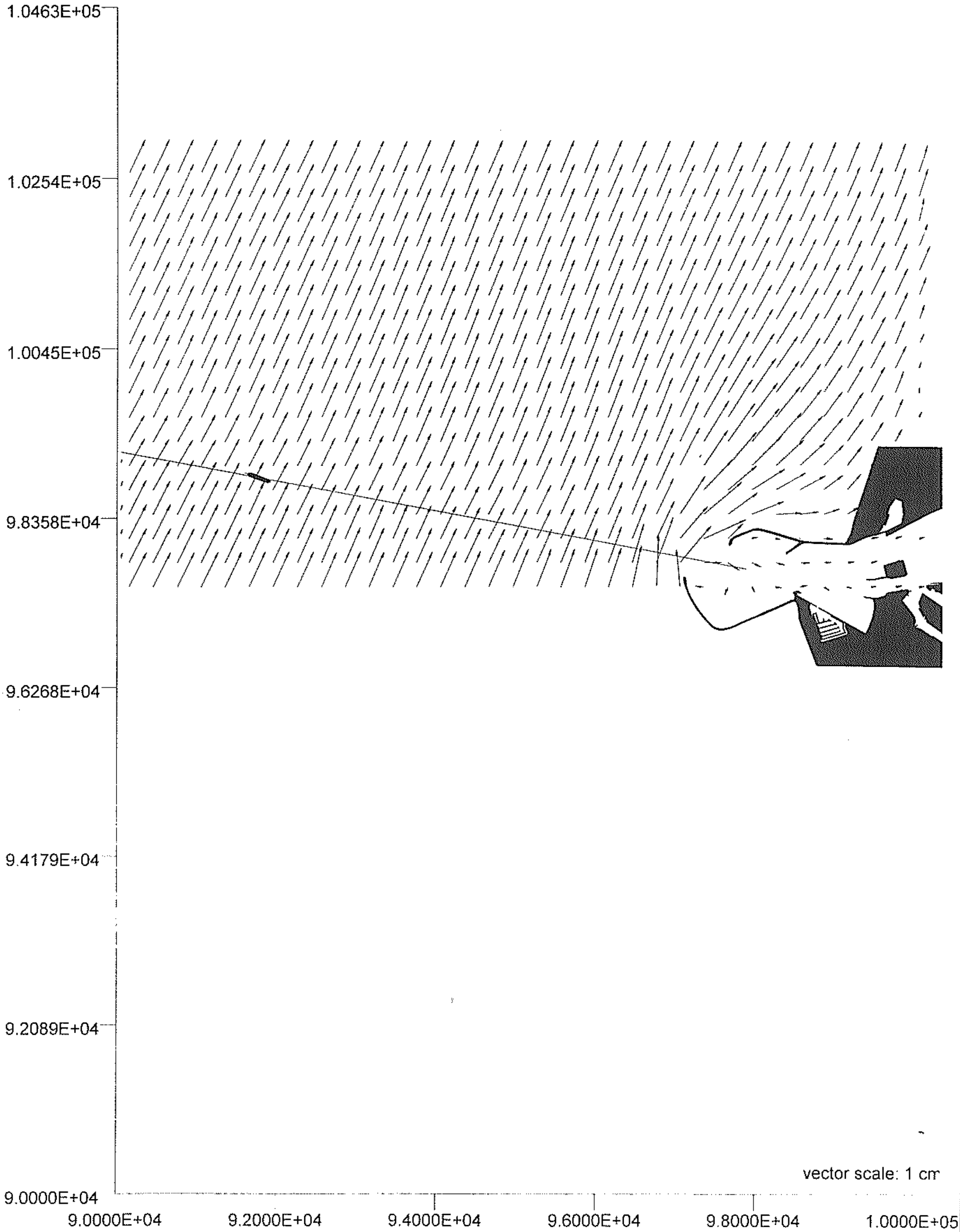
Current pattern near IJmuiden Spring tide, High Water -3 hours	R04	Figure 4
	W. Welvaarts	
AVV Transport Research Centre		

Alkyon 5/16/01 2 13 06 AM



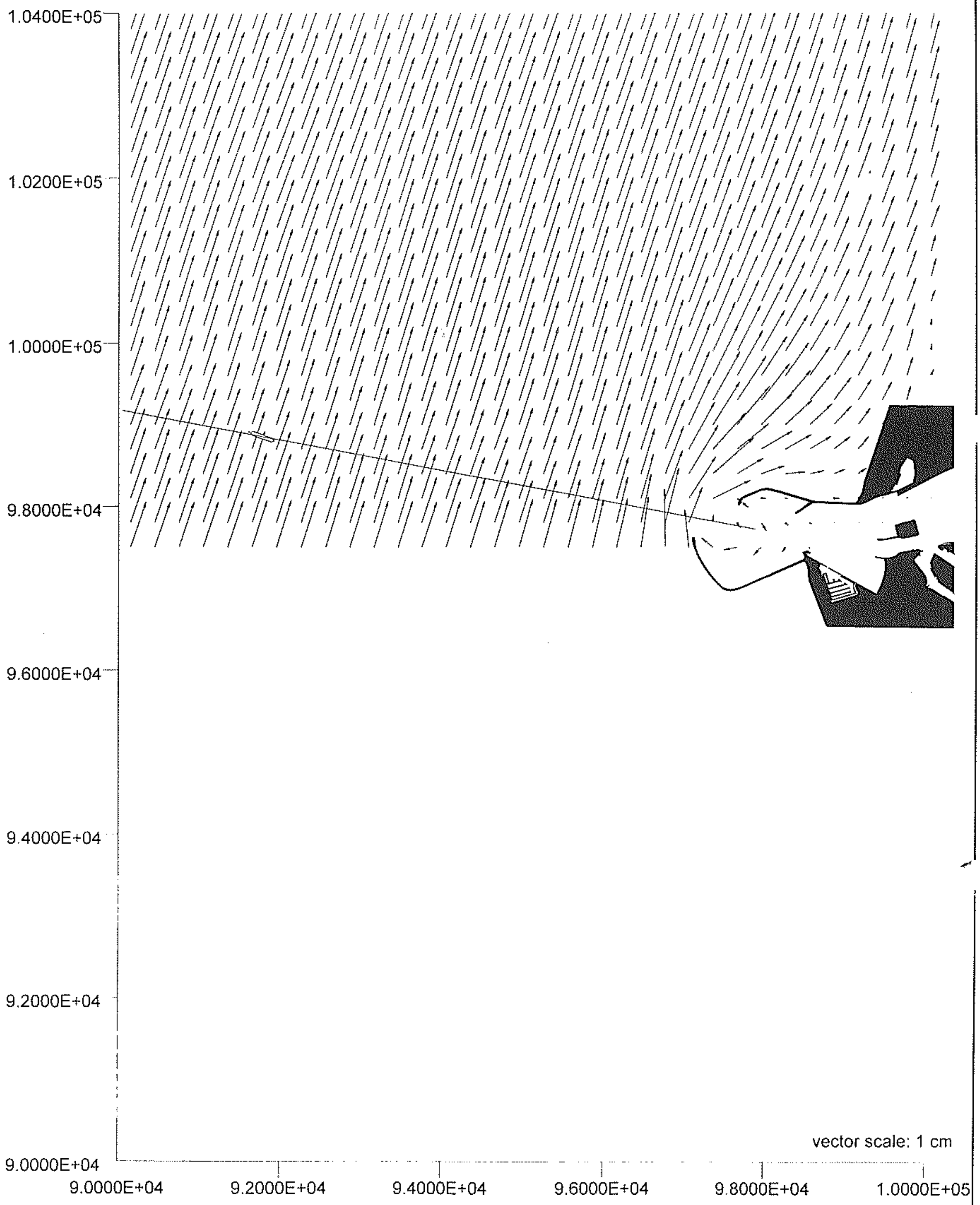
Current pattern near IJmuiden Spring tide, High Water -2 hours	R05	Figure 5
	W. Welvaarts	
AVV Transport Research Centre		

Alkyon 5/16/01 2 16 19 AM

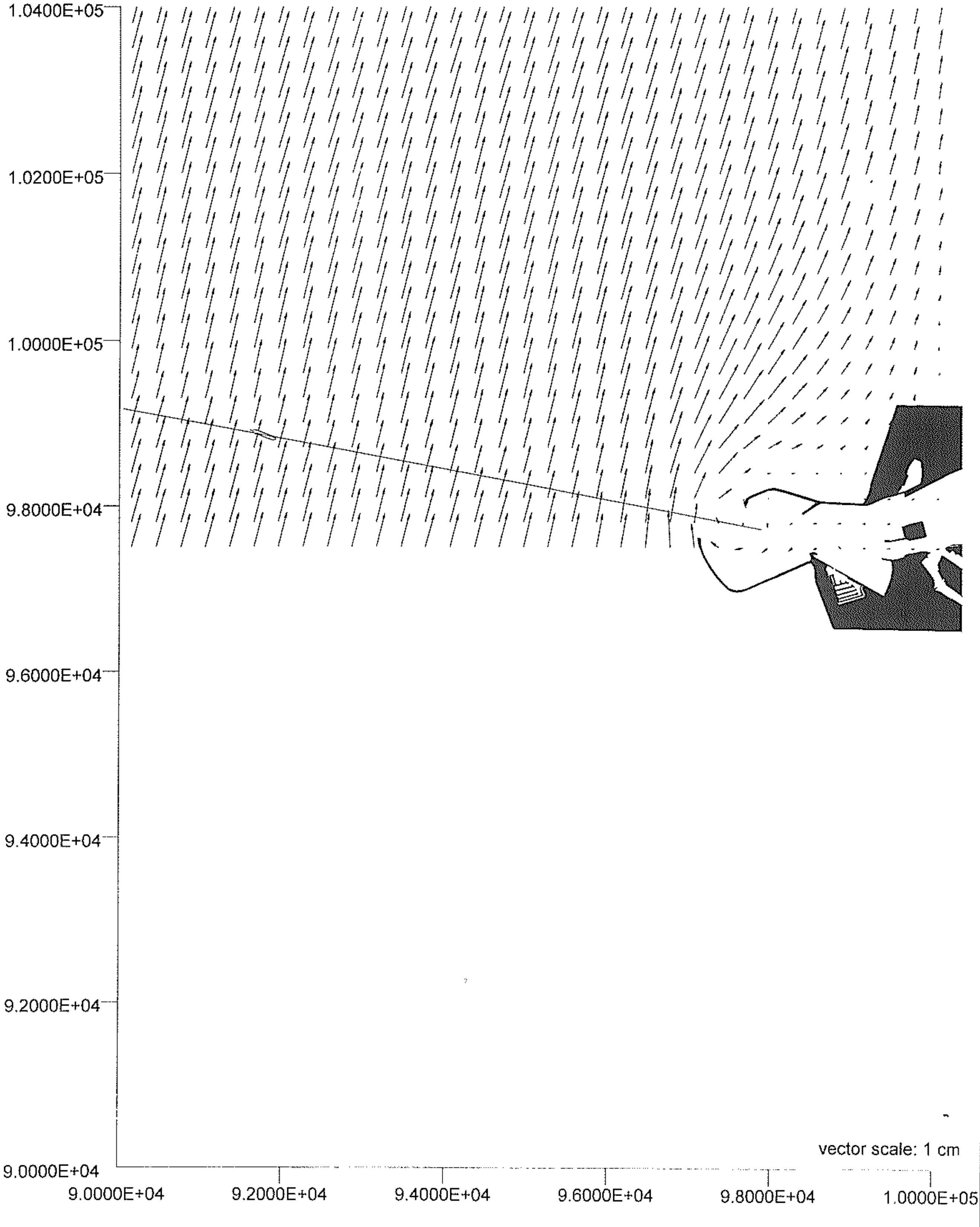


Current pattern near IJmuiden Spring tide, High Water -1 hours	R06	Figure 6
	W. Welvaarts	
AVV Transport Research Centre		

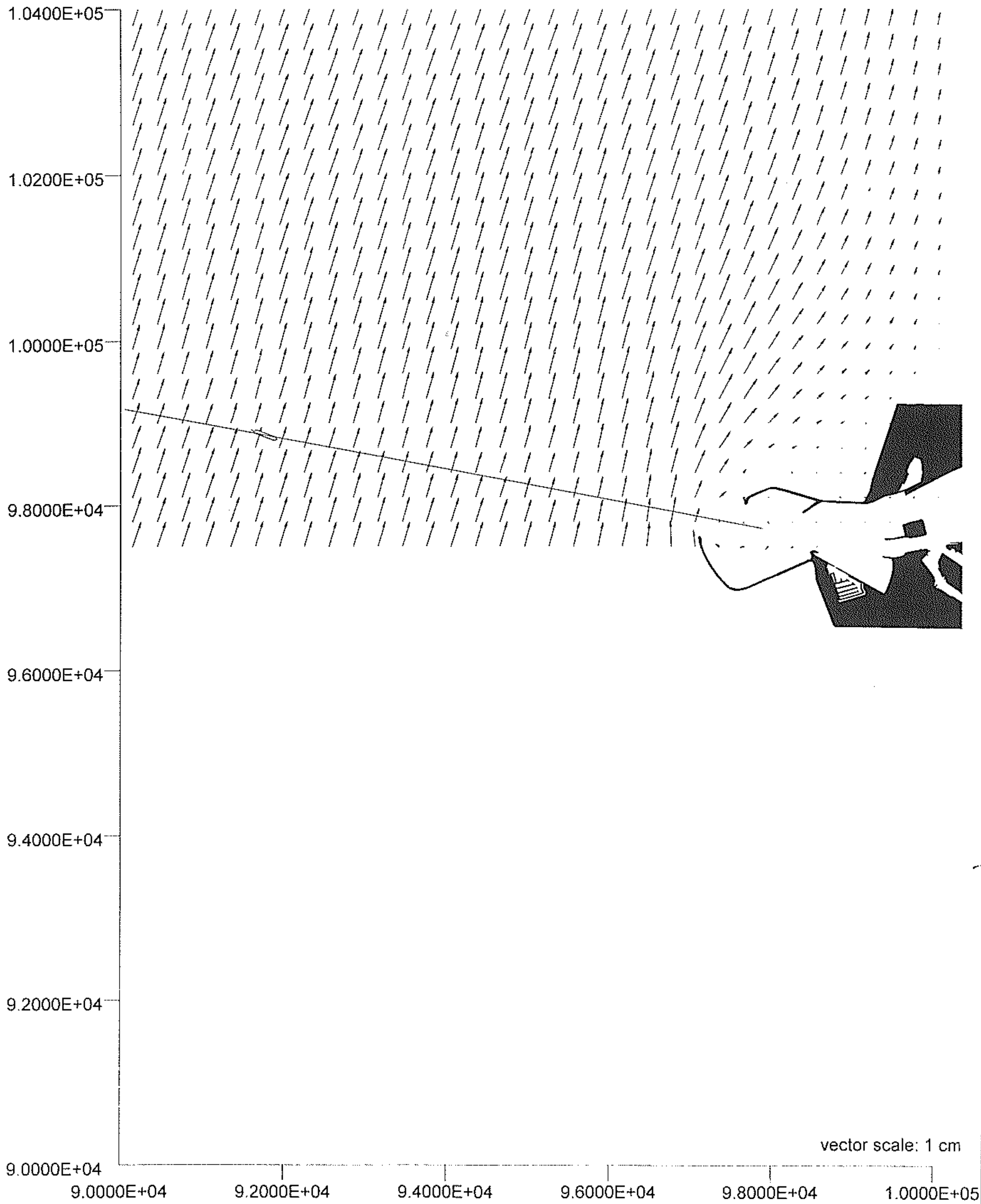
Alkyon 5/16/01 5 17 13 AM



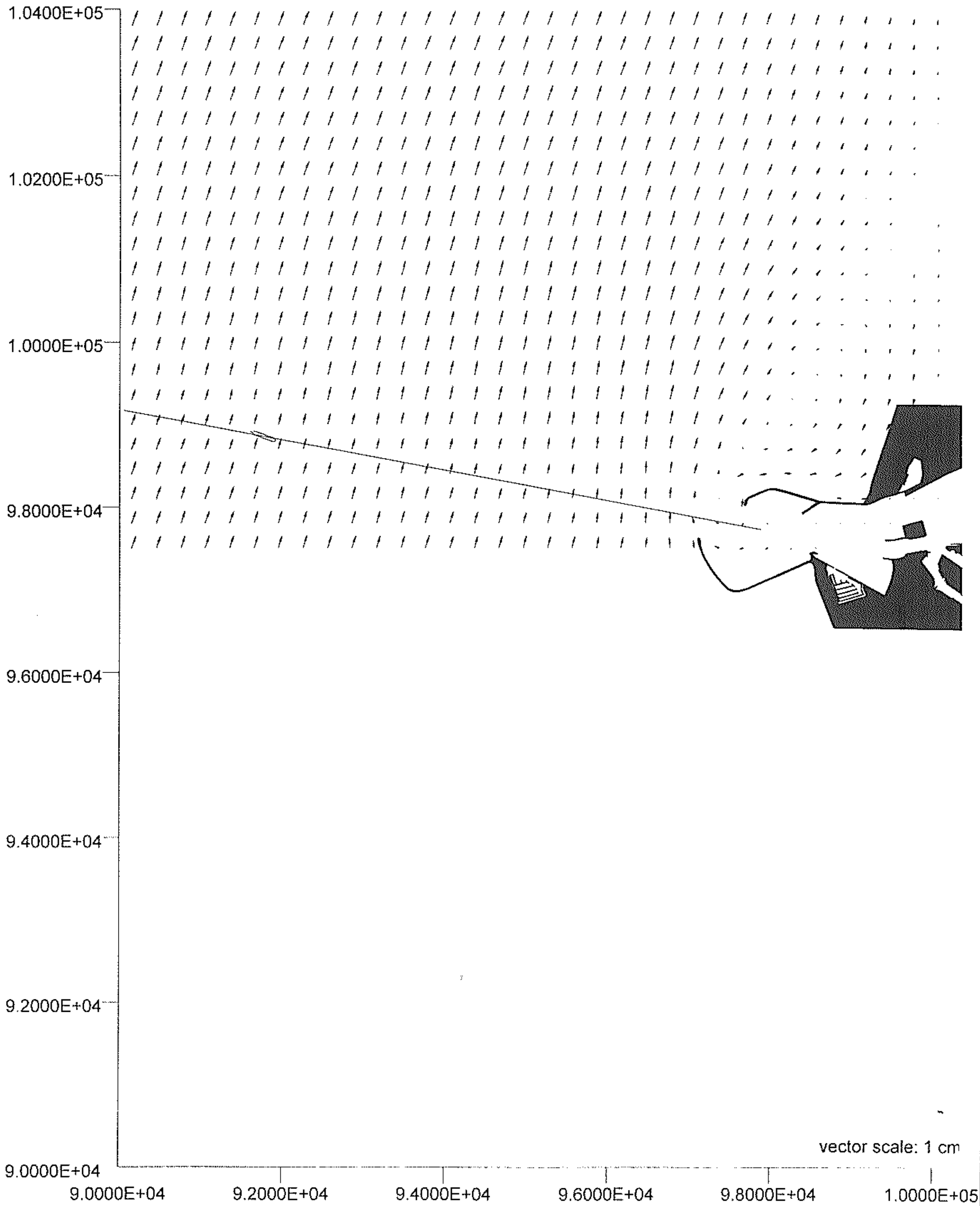
Current pattern near IJmuiden Spring tide, High Water	R07	Figure 7
	W. Welvaarts	
AVV Transport Research Centre		



Current pattern near IJmuiden Spring tide, High Water +1 hours	R08	Figure 8
	W. Welvaarts	
AVV Transport Research Centre		

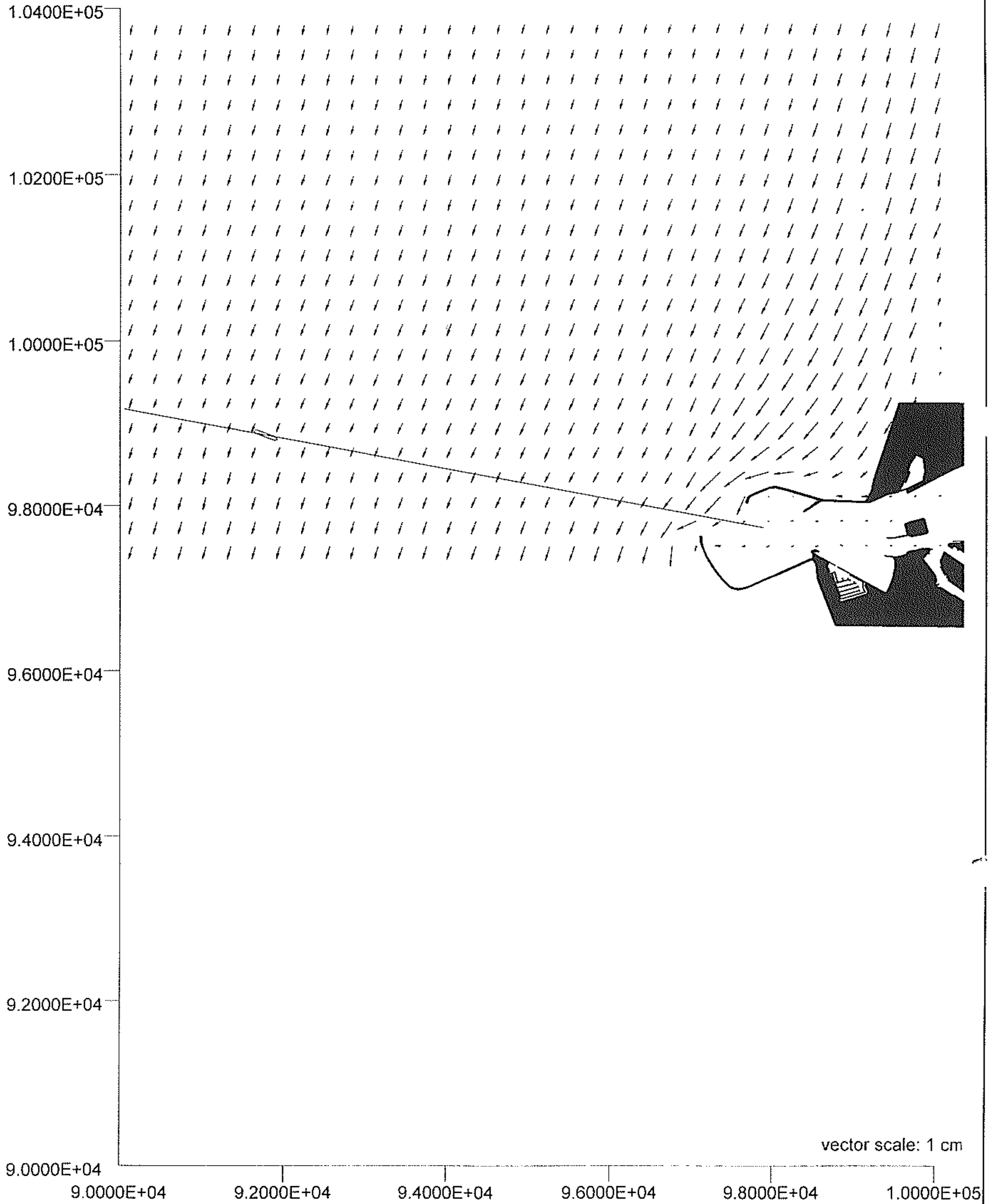


Current pattern near IJmuiden	R09	Figure 9
Spring tide, High Water +2 hours	W. Welvaarts	
AVV Transport Research Centre		

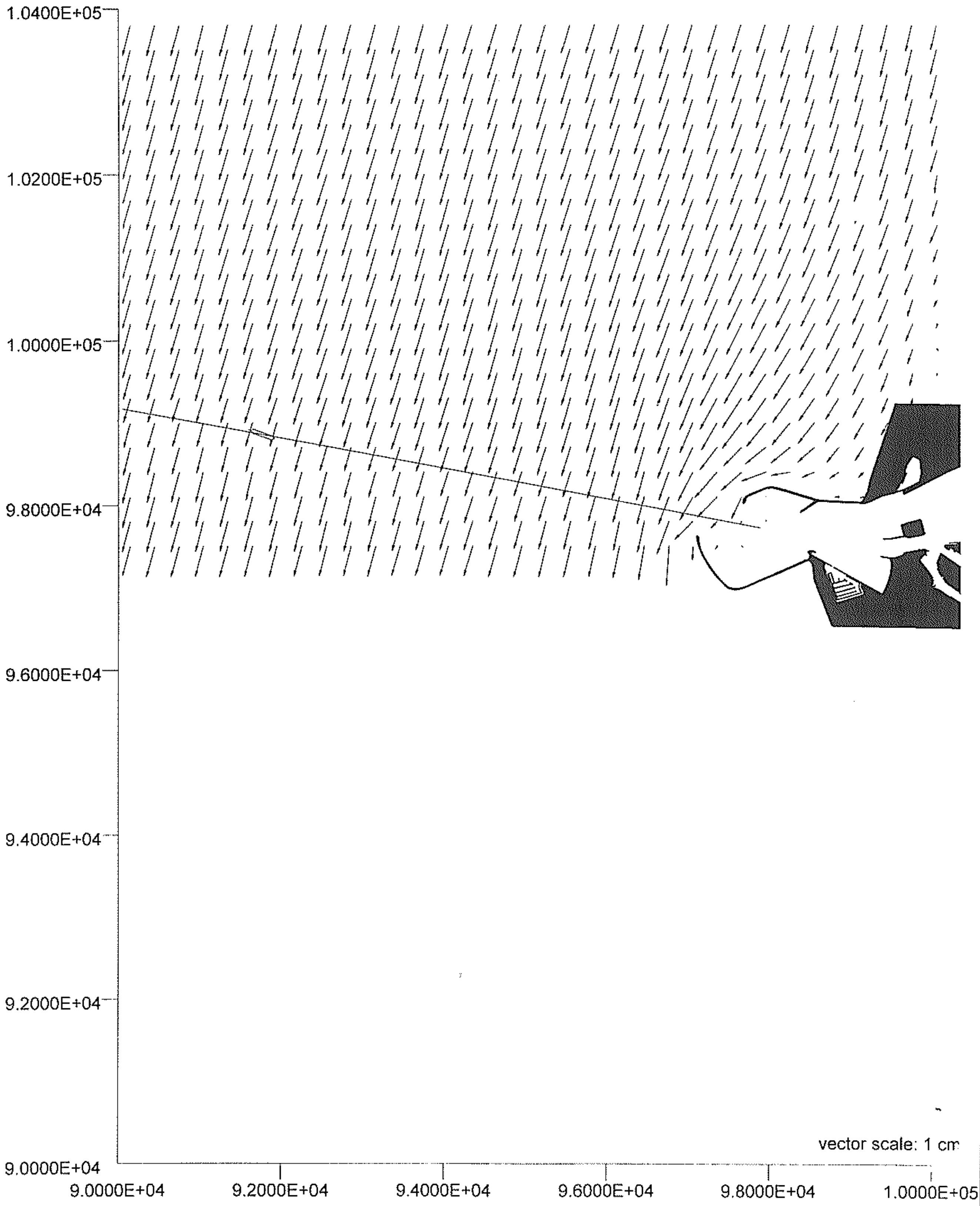


Current pattern near IJmuiden Spring tide, High Water +3 hours	R10	Figure 10
	W. Welvaarts	
AVV Transport Research Centre		

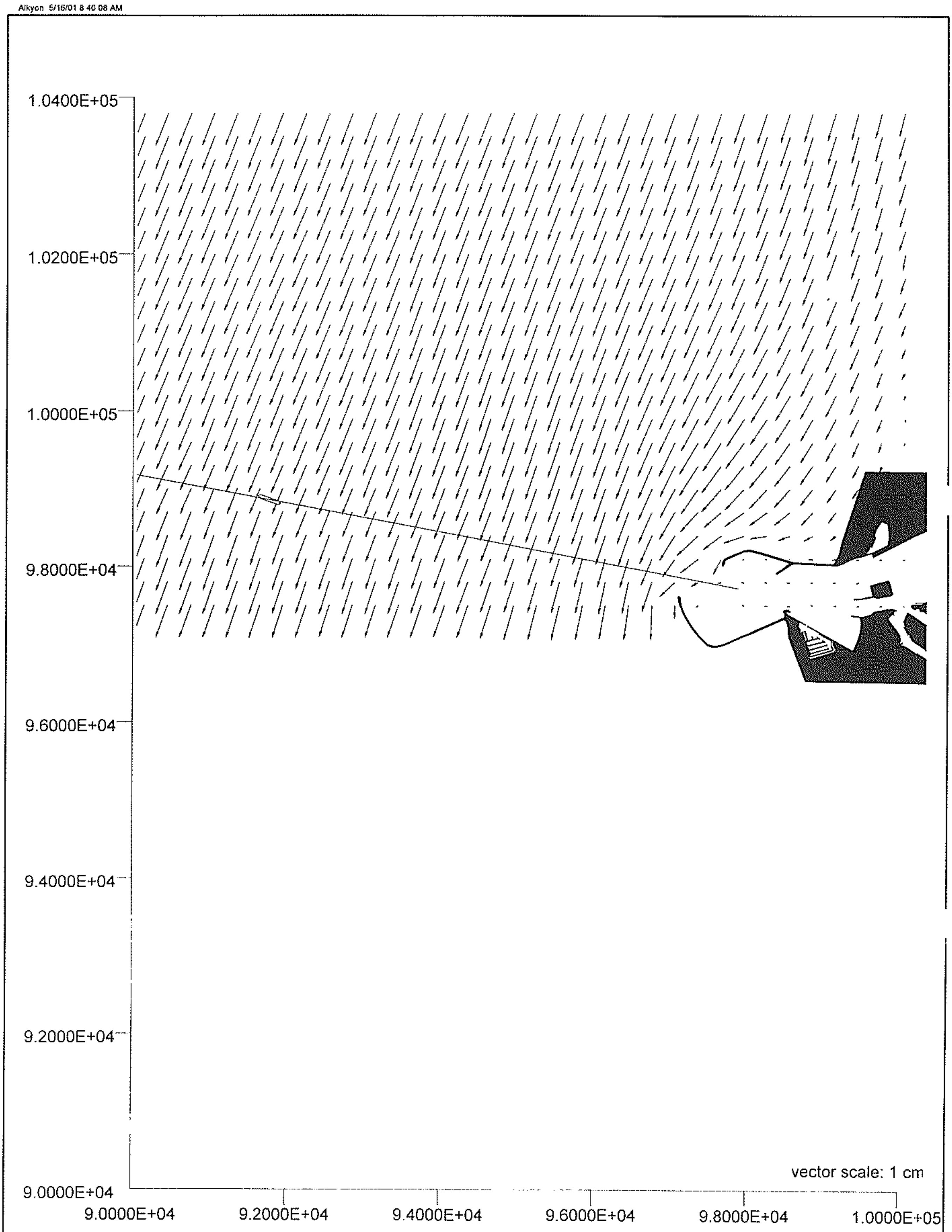
Alkyon 5/16/01 8 37 09 AM



Current pattern near IJmuiden Spring tide, High Water +4 hours	R11	Figure 11
	W. Welvaarts	
AVV Transport Research Centre		



Current pattern near IJmuiden Spring tide, High Water +5 hours	R12	Figure 12
	W. Welvaarts	
AVV Transport Research Centre		



Current pattern near IJmuiden Spring tide, High Water +6 hours	R13	Figure 13
	W. Welvaarts	
AVV Transport Research Centre		

Appendix VI: Wind- and wave rose

List of tables:

Table 1 Probability that highest of wind occur in the given speed and direction class near the IJgeul

Wind speed [m/s]	Wind direction [° north]												
Wv	**0:30**	**30:60**	**60:90**	**90-120**	**120:150**	**150:180**	**180:210**	**210:240**	**240:270**	**270:300**	**300:330**	**330:360**	**Total**
<2.50	0.365	0.376	0.328	1.001	1.181	0.740	0.624	0.583	0.503	0.463	0.457	0.418	7.041
2.50:5.00	1.549	1.541	1.945	3.080	2.917	3.026	1.362	1.679	1.870	1.803	1.498	1.721	23.992
5.00:7.50	1.484	1.491	3.450	1.647	1.105	3.213	2.575	3.552	2.856	2.151	1.723	2.326	27.574
7.50:10.00	0.795	0.729	2.181	0.328	0.129	1.011	2.440	5.042	2.865	1.723	1.385	1.384	20.013
10.00:12.50	0.187	0.238	0.671	0.102	0.003	0.243	1.785	4.477	1.842	1.186	0.981	0.625	12.340
12.50:15.00	0.044	0.009	0.158	0.028	0.000	0.053	0.908	2.175	0.888	0.671	0.587	0.248	5.769
15.00:17.50	0.004	0.000	0.005	0.000	0.000	0.015	0.430	0.805	0.395	0.474	0.218	0.080	2.427
17.50:20.00	0.000	0.000	0.000	0.000	0.000	0.000	0.094	0.249	0.196	0.156	0.046	0.006	0.747
20.00:22.50	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.023	0.044	0.004	0.002	0.000	0.084
22.50:25.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.008	0.000	0.000	0.000	0.013
													100.000
Total	4.429	4.385	8.738	6.185	5.335	8.303	10.229	18.591	11.467	8.630	6.899	6.811	100.000

Table 2 Probability that highest of sea and swell occur in the given height and direction class on open sea near the IJgeul [ref. 14]

Significant wave height [m]

	Wave direction [° north]												
Hs	**0:30**	**30:60**	**60:90**	**90-120**	**120:150**	**150:180**	**180:210**	**210:240**	**240:270**	**270:300**	**300:330**	**330:360**	**Total**
<0.50	1.688	0.944	0.519	0.348	0.445	0.537	0.756	1.270	1.749	1.589	1.898	2.448	14.191
0.50:1.00	3.918	2.167	1.381	0.897	1.019	1.173	1.803	4.440	2.887	2.302	2.902	5.402	30.291
1.00:1.50	2.158	1.342	0.915	0.530	0.391	0.609	1.504	4.298	2.298	1.940	2.399	4.496	22.880
1.50:2.00	0.863	0.690	0.337	0.149	0.106	0.259	1.001	3.491	1.853	1.459	1.718	2.428	14.354
2.00:2.50	0.310	0.238	0.139	0.025	0.009	0.085	0.524	2.525	1.273	1.036	0.983	1.158	8.305
2.50:3.00	0.122	0.085	0.063	0.005	0.009	0.011	0.261	1.481	0.870	0.683	0.580	0.546	4.716
3.00:3.50	0.045	0.016	0.013	0.000	0.007	0.027	0.130	0.796	0.441	0.384	0.357	0.331	2.547
3.50:4.00	0.018	0.002	0.002	0.000	0.000	0.009	0.043	0.310	0.259	0.279	0.240	0.214	1.376
4.00:4.50	0.005	0.011	0.002	0.000	0.000	0.004	0.013	0.110	0.149	0.173	0.095	0.110	0.672
4.50:5.00	0.000	0.004	0.000	0.000	0.000	0.000	0.005	0.040	0.076	0.088	0.065	0.086	0.364
5.00:5.50	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.038	0.038	0.022	0.034	0.148
5.50:6.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.018	0.032	0.016	0.034	0.104
6.00:6.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.014	0.009	0.005	0.014	0.044
6.50:7.00	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.004	0.006
7.00:7.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005
7.50:8.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.00:9.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	9.129	5.499	3.371	1.954	1.986	2.714	6.042	18.781	11.925	10.012	11.280	17.310	100.003

Table 3 Probability that highest of swell occur in the given height and direction class on open sea near the IJgeul

Significant wave height [m]	Wave direction [° north]												
Hs	**0:30**	**30:60**	**60:90**	**90:120**	**120:150**	**150:180**	**180:210**	**210:240**	**240:270**	**270:300**	**300:330**	**330:360**	**Total**
<0.20	5.742	1.264	0.410	0.290	0.265	0.230	0.610	2.049	2.543	3.323	11.743	33.645	62.114
0.20:0.40	0.899	0.085	0.005	0.000	0.000	0.005	0.005	0.760	1.174	0.740	3.043	16.400	23.116
0.40:0.60	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.275	0.385	0.235	0.755	5.477	7.317
0.60:0.80	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.180	0.060	0.395	2.109	2.864
0.80:1.00	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.070	0.040	0.220	0.939	1.309
1.00:1.20	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.010	0.025	0.110	0.575	0.770
1.20:1.40	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.045	0.005	0.060	0.420	0.555
1.40:1.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.035	0.000	0.075	0.240	0.365
1.60:1.80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.015	0.010	0.040	0.200	0.275
1.80:2.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.015	0.005	0.020	0.190	0.235
2.00:2.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.035	0.165	0.215
2.20:2.40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.005	0.020	0.150	0.185
2.40:2.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.010	0.005	0.015	0.080	0.115
2.60:2.80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.010	0.060	0.075
2.80:3.00	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.020	0.065	0.100
3.00:9.99	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.010	0.010	0.055	0.300	0.395
Total	6.941	1.349	0.415	0.290	0.265	0.235	0.615	3.269	4.522	4.473	16.616	61.015	100.005

Appendix VII: Procedure of entering the harbour

Table of contents:

1. General

1.1 Pre-entry report

Before arrival a pre-entry report has to be submitted to the Pilot VTS IJmuiden, the time of the reports is divided for each shipping category as follows. A ship with a draught (in salt water) of more than 13.7 metres or less than 16.5 metres (channel-bound ships) has to submit the report 8 hours before the arrival at the heli rendez-vous in the approach area to the IJgeul.

The contents of the report comprises of;

A Name, call sign, ship's flag
B Date and time in hours and minutes of the report
G Last port of call / berth on departure
I Harbour / berth of destination
J Date and time in hours and minutes at which the pilot is required at the usual place of pilotage / berth.
O Draught in metres
P Quantity and sort -incoming cargo
-outgoing cargo
-transit cargo
-dangerous cargo (IMO)
T Name / place / telephone (also outside office hours) of agent
U LOA, beam, GRT, dwt and ship's type
X -purpose of visit
-intended departure (date and time)
-destination
-required documents such as Expiring date of Certificate of Fitness, tanker checklist, Certificate of Liability and Certificate of Gasfree
-name of P and I-club

1.2 Pilotage

Information and advice with regard to pilotage can be obtained (24 hrs a day) from the pilotage co-ordinator of the Harbour Operational Centre (HOC) at IJmuiden. The pilotage co-ordinator also takes care of co-ordination and organisation of helicopter pilotage.

Pilotage of channel-bound ships
Ships constrained by their draught (draught in salt water more than 13.7 metres), are considered as channel-bound ships. Pilots will always board vessels constrained by their draught by helicopter, unless they have already been boarded elsewhere, near the rendez-vous point indicated on the nautical chart (52°30'N 3°50'E).

The exact position of boarding will be arranged in consultation between the helicopter and the ship. Before approaching the rendez-vous point, ships are advised, depending from which direction they come, to approach the way point in position 52°30'N 3°45'E. From this point they can proceed to the rendez-vous point. Channel-bound ships are boarded by two pilots.

1.3 Vessel Traffic Services (VTS)

The Harbour Operational Centre (HOC) at IJmuiden is the traffic control centre where on a continuos basis all operational activities concerning the smooth and safe handling of shipping are co-ordinated.

Appendix VIII: Probability distribution functions

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List of figures:

1. General

The required functions are given below. Some of the distribution functions have no closed form, Matlab can integrate the density function numerically, a PSD of this program is given in Chapter 2.

Gamma function:

$$\Gamma(\phi) = \int_0^\infty t^{\phi-1} \cdot e^{-t} \cdot \partial t \tag{1}$$

Beta (α_1,α_2)
Density:

$$f(x) = \frac{x^{\alpha_1-1} \cdot (1-x)^{\alpha_2-1}}{B(\alpha_1,\alpha_2)} \tag{2}$$

where $B(\alpha_1,\alpha_2) = \int t^{x_1-1} \cdot (1-t)^{x_2-1} \cdot \partial t$ (3)

The distribution has no closed form.

Erlang (m,β)
Density:

$$f(x) = \frac{\beta^{-m} \cdot x^{m-1} \cdot e^{-x/\beta}}{\Gamma(m)} \tag{4}$$

where Γ(m) is the Gamma function

The distribution has no closed form.

Gamma (α,β)
Density:

$$f(x) = \frac{\beta^{-\alpha} \cdot x^{\alpha-1} \cdot e^{-x/\beta}}{\Gamma(\alpha)} \tag{5}$$

where $\Gamma(\alpha)$ is the Gamma function

The distribution has no closed form.

Logistic(α,β)
Density:

$$f(x) = \frac{z}{\beta \cdot (1+z)^2} \tag{6}$$

where $z = \exp\left(\frac{-(x-\alpha)}{\beta}\right)$ (7)

Distribution:

$$F(x) = \frac{1}{1+z} \tag{8}$$

$$x(F) = -\beta \cdot \ln\left[\frac{1}{F-1}\right] + \alpha \tag{9}$$

Lognormal (μ,σ)
Density:

$$f(x) = \frac{1}{x \cdot \sqrt{2 \cdot \pi \cdot \sigma_1^2}} \cdot e^{\frac{-[\ln(x) - \mu_1]^2}{2 \cdot \sigma_1^2}} \tag{10}$$

where $$\mu_1 = \ln\left[\frac{\mu^2}{\sqrt{\sigma^2 + \mu^2}}\right] \tag{11}$$

$$\sigma_1 = \sqrt{\ln\left[\frac{\sigma^2 + \mu^2}{\mu^2}\right]} \tag{12}$$

The distribution has no closed form.

Lognormal2 (μ,σ)
Density:

$$f(x) = \frac{1}{x \cdot \sqrt{2 \cdot \pi \cdot \sigma^2}} \cdot e^{\frac{-[\ln(x) - \mu]^2}{2 \cdot \sigma^2}} \tag{13}$$

The distribution has no closed form.

Weibull (α,β)
Density:

$$f(x) = \alpha \cdot \beta^{-\alpha} \cdot x^{(\alpha-1)} \cdot e^{-\left[\frac{x}{\beta}\right]^{\alpha}} \tag{14}$$

Distribution:

$$F(x) = 1 - e^{-\left[\frac{x}{\beta}\right]^{\alpha}} \tag{15}$$

$$x(F) = -\ln(1-F)^{1/\alpha} \cdot \beta \tag{16}$$

2. PSD

In order to be able to apply the CDF method to the distribution functions that have no closed form, one can use the numerical distribution function. In figure 1 the PSD of the program written in Matlab is given.

```
for i:= 1 to 80
    z(i):= integrate ('density function', 0, i/10)
```

Figure 1 PSD for integrating the density function

In this example the program integrates the density function for a wave height up to 8 m, if the value 1.00 has not been reached yet one has to increase the wave height.

Appendix IX: Fitted distribution functions

List of tables:

Table 1 Distribution functions for the wind speed in the given direction class

Direction class	Distribution function	Parameters	
0-30°	Erlang	m = 4.00	$\beta = 1.43$
30-60°	Weibull	$\alpha = 2.26$	$\beta = 6.13$
60-90°	Logistic	$\alpha = 6.65$	$\beta = 1.42$
90-120°	Gamma	$\alpha = 4.02$	$\beta = 1.11$
120-150°	Logistic	$\alpha = 3.71$	$\beta = 1.14$
150-180°	Logistic	$\alpha = 5.41$	$\beta = 1.33$
180-210°	Logistic	$\alpha = 7.95$	$\beta = 2.44$
210-240°	Logistic	$\alpha = 9.25$	$\beta = 2.01$
240-270°	Logistic	$\alpha = 7.72$	$\beta = 2.39$
270-300°	Erlang	m = 3.00	$\beta = 2.67$
300-330°	Weibull	$\alpha = 2.09$	$\beta = 8.74$
330-360°	Erlang	m = 4.00	$\beta = 1.67$

Table 2 Distribution functions for the wave height in the given direction class (swell)

Direction class	Distribution function	Parameters	
0-30°	Lognormal2	$\mu = -2.40$	$\sigma = 0.98$
210-240°	Lognormal2	$\mu = -1.69$	$\sigma = 0.94$
240-270°	Lognormal2	$\mu = -1.59$	$\sigma = 0.94$
270-300°	Lognormal2	$\mu = -2.14$	$\sigma = 1.04$
300-330°	Lognormal2	$\mu = -2.04$	$\sigma = 1.06$
330-360°	Lognormal2	$\mu = -1.56$	$\sigma = 0.92$

Table 3 Distribution functions for the wave height in the given direction class

Direction class	Distribution function	Parameters	
0-30°	Gamma	$\alpha = 2.75$	$\beta = 0.35$
30-60°	Gamma	$\alpha = 2.83$	$\beta = 0.36$
60-90°	Gamma	$\alpha = 3.09$	$\beta = 0.33$
90-120°	Logistic	$\alpha = 0.84$	$\beta = 0.27$
120-150°	Lognormal	$\mu = 0.89$	$\sigma = 0.56$
150-180°	Lognormal	$\mu = 1.04$	$\sigma = 0.73$
180-210°	Gamma	$\alpha = 2.80$	$\beta = 0.46$
210-240°	Erlang	m = 3.00	$\beta = 0.52$
240-270°	Gamma	$\alpha = 2.12$	$\beta = 0.70$
270-300°	Gamma	$\alpha = 1.96$	$\beta = 0.78$
300-330°	Gamma	$\alpha = 2.01$	$\beta = 0.68$
330-360°	Lognormal	$\mu = 1.34$	$\sigma = 1.08$

Appendix X: Review runs

List of tables:

Table 1 Fast time runs

Input											Output				
run	tide	hours HW	wind dir. [°]	wind vel. [m/sec]	swell dir. [°]	swell height [m]	F [-]	max. current velocity [m/sec]	water level [m]	rudder > 20 ° [m]	power burst [m]	max. drift angle [°]	entrance speed [m/sec]	judgement
1	neap	-1	238	9.8	14	0.13	0.7025	0.5	0.37	540	350	9	3.4	U
2	average	+1	291	8.7	341	0.33	0.8208	0.49	0.89	250	100	9	3.2	F
3	spring	+5	302	7.3	335	0.19	1.0117	0.54	0.08	490	0	9	3.1	C
4	spring	+5	273	16.6	265	0.12	0.932	0.49	0.08	510	0	8	3.2	C
5	average	+1	328	11	333	0.31	0.7663	0.46	0.89	200	30	8	3.2	F
6	spring	+2	211	11.7	347	0.27	1.2725	0.53	0.69	600	160	10	3.2	U
7	average	+1	29	8.3	304	0.32	0.7763	0.46	0.89	570	100	8	3.2	U
8	average	+1	278	7.8	340	0.02	0.8323	0.5	0.89	480	130	9	3.2	C
9	average	+5	329	15.7	239	0.24	0.9302	0.49	0.08	730	60	9	3.2	U
10	average	+1	296	17.4	340	0.08	0.7778	0.46	0.89	540	160	10	3.4	C
11	average	+1	243	9.3	353	0.27	0.9068	0.54	0.89	640	160	10	3.2	U
12	neap	+1	195	14.8	331	0.1	0.9698	0.58	0.71	830	220	11	3.2	U
13	neap	+1	215	14.8	346	0.12	0.8913	0.53	0.71	850	200	10	3.3	U
14	average	+1	253	13.7	337	0.36	0.9505	0.57	0.89	720	200	10	3.3	U
15	spring	+5	339	7	355	0.37	1.0292	0.55	0.08	520	0	10	3.1	C
16	spring	+1	322	9.4	222	0.3	0.951	0.57	1.01	250	130	10	3.2	F
17	average	+1	275	7.1	326	0.07	0.8361	0.5	0.89	330	130	9	3.3	F
18	average	-1	305	12.6	352	0.07	0.7853	0.56	0.47	530	330	11	3.5	U
19	average	-1	86	9	0	0.03	0.8173	0.58	0.47	520	330	11	3.3	U
20	average	+1	212	9.1	339	0.1	0.9651	0.58	0.89	670	160	10	3.2	U
21	average	+1	63	10.4	331	1.12	0.7855	0.47	0.89	190	60	8	3.1	F
22	average	-1	271	7.8	349	0.24	0.8423	0.6	0.47	560	390	11	3.5	U
23	average	+5	13	8.5	340	0.05	0.8824	0.47	0.08	520	0	8	3.1	C
24	spring	+5	301	11	336	0.72	1.0255	0.54	0.08	560	0	9	3.1	U
25	spring	+1	336	7.8	349	0.11	0.9543	0.57	1.01	290	130	10	3.2	F
26	spring	+2	214	8.5	309	0.35	1.14	0.48	0.69	450	100	8	3.2	C
27	neap	+0	295	8.7	355	0.11	0.6207	0.54	0.85	650	200	10	3.3	U
28	neap	+0	100	8.6	348	0.08	0.6307	0.55	0.85	510	190	10	3.2	C
29	spring	+2	241	17.4	343	0.11	1.3416	0.56	0.69	840	370	10	3.3	U
30	spring	+5	348	11.9	345	1.16	1.0963	0.58	0.08	680	90	10	3.1	U
31	neap	+0	85	8.6	335	0.13	0.6206	0.54	0.85	320	160	10	3.2	U
32	neap	-1	216	8.8	315	0.17	0.7197	0.51	0.37	550	340	9	3.3	U
33	neap	-1	270	8.5	312	0.06	0.6433	0.46	0.37	500	260	9	3.3	C

34	average	+1	70	15	344	0.29	0.7565	0.45	0.89	180	0	8	3	F
35	neap	-1	248	10.3	355	0.27	0.6918	0.49	0.37	540	350	9	3.4	U
36	spring	+2	218	8.4	360	0.35	1.1252	0.47	0.69	510	100	8	3.2	C
37	average	+1	225	11.2	338	0.33	0.9947	0.59	0.89	570	160	9	3.2	U
38	neap	-1	246	9	345	0.29	0.6805	0.48	0.37	540	350	9	3.4	U
39	average	+5	61	9.9	325	0.18	0.8616	0.46	0.08	190	0	8	3.1	F
40	spring	+2	226	9.5	316	0.22	1.1417	0.48	0.69	510	130	8	3.2	C
41	average	+5	316	9.5	342	0.11	0.8567	0.45	0.08	490	0	8	3.1	C
42	spring	+2	216	7.6	354	0.07	1.1059	0.46	0.69	480	130	8	3.2	C
43	neap	-1	235	11.3	332	0.09	0.7337	0.52	0.37	570	350	9	3.4	U
44	neap	+0	325	8.1	14	0.16	0.6051	0.53	0.85	520	200	10	3.3	C
45	spring	+5	305	10.3	262	0.09	1.0267	0.54	0.08	520	0	9	3.1	C
46	neap	+0	147	7	346	0.21	0.6722	0.59	0.85	670	220	11	3.2	U
47	spring	+5	2	10.3	360	0.06	1.0871	0.58	0.08	660	70	10	3.3	U
48	neap	-1	222	7.3	355	0.58	0.6861	0.49	0.37	540	320	9	3.4	U
49	spring	+2	205	11.1	359	0.09	1.2692	0.53	0.69	600	190	10	3.2	U
50	spring	+2	238	11.2	354	0.16	1.1516	0.48	0.69	510	130	8	3.2	C
51	spring	+5	61	7.1	332	0.25	1.0196	0.54	0.08	310	0	10	3.1	F

Table 2 Cond_26 (spring tide, HW +2 hours, wind 8.5 m/sec 214°, swell 0.35 m 309°)

run	distance rudder angle>20° [m]	distance power burst [m]	max. drift angle [°]	speed at entrance harbour [m/sec]	judgement
26_1	310	190	8	3.25	C
26_2	400	220	8	3.25	C
26_3	190	220	8	3.35	C
26_5	190	130	8	3.3	F
26_8	220	190	8	3.35	C
26_9	310	120	8	3.25	F
26_10	250	190	8	3.28	C
26_11	280	160	8	3.25	C
26_13	240	190	8	3.3	C
26_14	250	160	8	3.25	C
26_15	190	160	8	3.3	C
26_17	250	160	8	3.3	C
26_18	200	80	8	3.26	F
26_19	140	60	8	3.25	F
26_20	230	90	8	3.27	F
26_21	250	60	8	3.24	F
26_22	280	120	8	3.24	F
26_23	260	60	8	3.25	F
26_24	310	60	8	3.24	F
26_25	260	60	8	3.24	F
mean	251	134	8	3.27	

Table 3 Cond_44 (neap tide, HW +0 hours, wind 8.1 m/sec 325°, swell 0.16 m 14°)

run	distance rudder angle>20° [m]	distance power burst [m]	max. drift angle [°]	speed at entrance harbour [m/sec]	judgement
44_1	260	290	10	3.4	C
44_2	240	190	9	3.35	C
44_3	260	260	8	3.4	C
44_8	250	250	9	3.3	C
44_10	270	220	9	3.3	C
44_11	240	220	9	3.3	C
44_12	310	140	9	3.3	F
44_13	340	170	9	3.28	C
44_14	340	130	9	3.28	F
44_16	360	170	9	3.32	C
44_17	310	110	9	3.3	F
44_18	310	200	9	3.29	C
44_19	310	140	9	3.27	F
44_20	410	140	9	3.29	C
44_21	310	130	9	3.3	F
44_22	390	170	10	3.28	F
44_23	310	220	9	3.29	C
44_24	410	130	9	3.27	C
44_25	250	140	9	3.3	F
44_26	310	140	9	3.3	F
mean	310	178	9.1	3.31	

Table 4 Cond_51 (spring tide, HW +5 hours, wind 7.1 m/sec 61°, swell 0.25 m 332°)

run	distance rudder angle>20° [m]	distance power burst [m]	max. Drift angle [°]	speed at entrance harbour [m/sec]	judgement
51_2	160	140	-10	3	C
51_4	210	100	-9	3.05	F
51_5	290	60	-9	3.05	F
51_6	270	60	-9	3.05	F
51_7	240	60	-9	3.05	F
51_8	230	120	-9	3.05	F
51_9	290	60	-9	3.04	F
51_10	260	120	-9	3.04	F
51_11	200	120	-9	3.03	F
51_12	170	90	-9	3.04	F
51_13	230	60	-9	3.03	F
51_14	160	60	-9	3.04	F
51_15	230	60	-9	3.02	F
51_16	170	90	-9	3.03	F
51_17	150	90	-9	3.06	F
51_18	230	60	-9	3.03	F
51_19	250	60	-9	3.03	F
51_20	260	60	-9	3.02	F
51_21	200	120	-9	3.05	F
51_22	170	60	-9	3.03	F
mean	219	83	-9.1	3.04	

Appendix XI: NAVSIM output data

List of tables:

Table 1 Fast time runs

run	tide	hours HW	wind dir. [°]	wind vel. [m/sec]	swell dir. [°]	swell height [m]	F [-]	max. current velocity [m/sec]	water level [m]	max. port side [m]	min. port side [m]	min. starboard [m]	max. starboard [m]	swept path [m]	average drift angle [°]
2	average	+1	291	8.7	341	0.33	0.8208	0.49	0.89	51.3368	25.165	-45.9422	-25.3367	97.279	106.5087
3	spring	+5	302	7.3	335	0.19	1.0117	0.54	0.08	50.3874	29.3216	-47.096	-26.1454	97.4834	93.8199
4	spring	+5	273	16.6	265	0.12	0.932	0.49	0.08	46.974	29.2971	-44.7739	-25.2773	91.7479	94.5323
5	average	+1	328	11	333	0.31	0.7663	0.46	0.89	48.8576	25.0585	-44.6872	-24.4982	93.5448	106.0588
8	average	+1	278	7.8	340	0.02	0.8323	0.5	0.89	52.2212	25.7659	-46.3573	-24.6835	98.5785	106.6255
10	average	+1	296	17.4	340	0.08	0.7778	0.46	0.89	55.8109	24.8279	-49.8205	-25.8062	105.6314	107.5625
15	spring	+5	339	7	355	0.37	1.0292	0.55	0.08	50.7896	29.9392	-48.1171	-25.931	98.9067	93.6668
16	spring	+1	322	9.4	222	0.3	0.951	0.57	1.01	54.9095	25.7295	-49.7415	-25.371	104.651	107.412
17	average	+1	275	7.1	326	0.07	0.8361	0.5	0.89	51.2106	25.2554	-46.9529	-25.1056	98.1635	106.5879
21	average	+1	63	10.4	331	1.12	0.7855	0.47	0.89	50.4169	25.7987	-45.5237	-24.2765	95.9406	106.3758
23	average	+5	13	8.5	340	0.05	0.8824	0.47	0.08	47.2017	29.7872	-45.3197	-25.2711	92.5214	94.5222
25	spring	+1	336	7.8	349	0.11	0.9543	0.57	1.01	55.6329	24.712	-49.7976	-25.4876	105.4305	107.4313
26	spring	+2	214	8.5	309	0.35	1.14	0.48	0.69	50.1753	23.7349	-45.5993	-25.1599	95.7746	106.4144
28	neap	+0	100	8.6	348	0.08	0.6307	0.55	0.85	58.7261	26.2825	-51.2524	-24.7285	109.9785	107.8461
33	neap	-1	270	8.5	312	0.06	0.6433	0.46	0.37	53.1759	25.8813	-45.6294	-22.0795	98.8053	106.6323
34	average	+1	70	15	344	0.29	0.7565	0.45	0.89	50.1709	25.7531	-44.8835	-23.4028	95.0544	106.3162
36	spring	+2	218	8.4	360	0.35	1.1252	0.47	0.69	49.132	24.7509	-45.1117	-25.3764	94.2437	106.3654
39	average	+5	61	9.9	325	0.18	0.8616	0.46	0.08	47.0597	29.4221	-45.9877	-25.7292	93.0474	94.5173
40	spring	+2	226	9.5	316	0.22	1.1417	0.48	0.69	49.6131	24.0381	-45.5306	-25.4412	95.1437	106.4377
41	average	+5	316	9.5	342	0.11	0.8567	0.45	0.08	45.994	29.0717	-43.9388	-25.3672	89.9328	94.801
42	spring	+2	216	7.6	354	0.07	1.1059	0.46	0.69	49.2421	24.0955	-45.0987	-25.0527	94.3408	106.2526
44	neap	+0	325	8.1	14	0.16	0.6051	0.53	0.85	56.0298	26.5017	-48.674	-24.3949	104.7038	107.3312
45	spring	+5	305	10.3	262	0.09	1.0267	0.54	0.08	50.4218	29.4638	-47.9198	-26.1338	98.3416	93.706
50	spring	+2	238	11.2	354	0.16	1.1516	0.48	0.69	50.1117	24.5061	-45.3321	-25.2799	95.4438	106.4946
51	spring	+5	61	7.1	332	0.25	1.0196	0.54	0.08	50.9401	29.9669	-47.3698	-25.801	98.3099	93.6105

Table 2 Cond_26 (spring tide. HW +2 hours. wind 8.5 m/sec 214°. swell 0.35 m 309°)

	max. port side [m]	min. port side [m]	min. starboard [m]	max. starboard [m]	swept path [m]	average drift angle [°]
26_1	50.308	3.8154	-50.9672	-36.0348	101.2752	106.65
26_2	54.3302	8.6926	-59.6858	-32.4181	114.016	107.1512
26_3	54.657	0.5822	-50.3595	-33.1096	105.0165	107.0532
26_5	51.8927	16.838	-47.4267	-23.8333	99.3194	106.7644
26_8	68.3009	37.9211	-45.3525	-7.3373	113.6534	105.9554
26_9	59.3677	16.5499	-45.6543	-21.6996	105.022	106.7422
26_10	53.7568	7.5576	-61.0051	-25.8298	114.7619	107.1453
26_11	60.3429	26.9776	-45.2427	-16.4022	105.5856	106.6165
26_13	50.3258	7.3642	-59.9272	-31.3531	110.253	107.1019
26_14	51.1077	1.978	-63.2251	-32.6116	114.3328	107.2407
26_15	58.0173	23.248	-46.9183	-19.7856	104.9356	106.7095
26_17	52.9482	4.5676	-57.2061	-29.6003	110.1543	107.1344
26_18	58.0975	37.7161	-45.2437	-9.0631	103.3412	105.8931
26_19	60.3201	43.2321	-45.348	-2.6072	105.6681	105.7479
26_20	57.3865	33.1295	-45.0641	-14.5072	102.4506	105.9796
26_21	56.7199	29.401	-45.1362	-16.4711	101.8561	106.2257
26_22	57.0365	30.1614	-45.2795	-18.1881	102.316	106.2447
26_23	58.2231	30.2714	-44.8296	-15.3562	103.0527	106.1619
26_24	57.5588	24.4721	-45.401	-19.4876	102.9598	106.3987
26_25	55.1158	24.4632	-44.8829	-19.8219	99.9987	106.4505
mean	56.29067	20.44695	-49.7078	-21.2759	105.99845	106.5683

Table 3 Cond_44 (neap tide. HW +0 hours. wind 8.1 m/sec 325°. swell 0.16 m 14°)

	max. port side [m]	min. port side [m]	min. starboard [m]	max. starboard [m]	swept path [m]	average drift angle [°]
44_1	54.3309	-15.5011	-67.6761	-42.2006	122.007	108.4399
44_2	68.1566	22.1478	-46.2274	-19.8337	114.384	107.5577
44_3	78.9662	45.2399	-44.9012	-3.8566	123.8674	107.0408
44_8	57.1162	0.6437	-62.9031	-34.8209	120.0193	108.2488
44_10	61.1484	26.2852	-46.8782	-21.295	108.0266	107.4725
44_11	62.1458	33.1727	-46.5073	-15.008	108.6531	107.3067
44_12	64.7423	37.3932	-46.7486	-12.6018	111.4909	107.1011
44_13	49.8771	5.0504	-71.583	-34.3838	121.4601	108.3498
44_14	52.7394	8.3545	-55.5157	-33.2358	108.2551	108.0009
44_16	51.3739	-6.1046	-67.9496	-40.7173	119.3235	108.409
44_17	57.0494	22.162	-51.1925	-23.2005	108.2419	107.7388
44_18	54.2884	13.2839	-55.3756	-33.0163	109.664	107.9442
44_19	54.3868	6.7851	-63.2187	-32.6863	117.6055	108.1777
44_20	53.5174	-4.6914	-64.5299	-41.6595	118.0473	108.337
44_21	55.7829	13.147	-48.3604	-33.0906	104.1433	107.8181
44_22	52.6895	-7.8034	-65.3025	-44.421	117.992	108.4184
44_23	54.2908	5.8892	-63.9945	-34.773	118.2853	108.208
44_24	57.2961	22.7202	-47.6694	-24.6496	104.9655	107.6281
44_25	61.8049	42.9855	-46.7184	-9.6624	108.5233	106.7864
44_26	67.3248	39.3726	-46.5544	-10.4931	113.8792	107.0144
mean	58.45139	15.52662	-55.4903	-27.2803	113.94172	107.7999

Table 4 Cond_51 (spring tide. HW +5 hours. wind 7.1 m/sec 61°. swell 0.25 m 332°)

	max. port side [m]	min. port side [m]	min. starboard [m]	max. starboard [m]	swept path [m]	average drift angle [°]
55_2	56.4601	23.3546	-60.4012	-35.2951	116.8613	92.9657
55_4	47.833	33.9237	-57.6907	-19.449	105.5237	93.131
55_5	48.1553	24.2399	-61.9681	-32.6021	110.1234	93.5914
55_6	48.233	24.155	-62.4328	-31.658	110.6658	93.5502
55_7	48.2225	21.9799	-59.585	-31.8661	107.8075	93.6467
55_8	48.4539	15.2969	-62.2371	-39.0808	110.691	93.7874
55_9	48.5647	17.4523	-64.3746	-36.0978	112.9393	93.7411
55_10	48.7502	14.9406	-63.5129	-41.2684	112.2631	93.8337
55_11	48.5853	33.0164	-56.7038	-23.3347	105.2891	93.1443
55_12	48.4002	16.0333	-61.6648	-35.0711	110.065	93.7229
55_13	48.4241	24.4519	-62.162	-32.237	110.5861	93.4958
55_14	48.4517	28.9163	-58.5278	-28.541	106.9795	93.3816
55_15	47.7618	17.5447	-65.0698	-39.5966	112.8316	93.6803
55_16	48.3189	28.7177	-61.8856	-26.4661	110.2045	93.3753
55_17	48.3337	18.6928	-63.1424	-37.1063	111.4761	93.7084
55_18	48.4026	19.6481	-64.1733	-36.6839	112.5759	93.6505
55_19	48.3365	28.2076	-62.778	-25.4075	111.1145	93.3532
55_20	48.3132	24.2018	-62.9701	-31.6051	111.2833	93.4711
55_21	48.3655	28.4756	-60.3839	-20.9265	108.7494	93.0603
55_22	48.3639	23.2546	-60.7409	-34.3394	109.1048	93.5087
mean	48.73651	23.32519	-61.6202	-31.9316	110.35675	93.48998

Appendix XII: Xtremes

Table of contents:

1. General

The computer program Xtremes deals with the statistical modelling and analysis of extremes. The analysis of extreme values must be embedded in other various approaches of main stream statistics such as data analysis, non-parametric curve estimation, survival analysis, time series analysis, regression analysis, robust statistics and parametric inference. In the textbook of the program these approaches are further elaborated, below the program itself is described.

2. Format of data sets

Data sets are stored as plain ASCII files. Certain specifications must be given at the top of the file, such as the type of the data set and the sample size. Moreover, one may include a shorter and a more detailed description. Data sets can be entered by utilising any text editor available under MS-DOS or Windows or by the integrated editor. First an example is given of an univariate data set;

```
Xtremes Univariate Data
Type: Artificial example
\begin (description)
This is an artificial data set. It was entered using the XPL editor.
\end (description)
Sample Size: 4
1
3.5
7
-4
```

After having typed the text, the data become active when it is saved to a file. One may also simulate a data set of the desired type using the option Generate... to obtain a complete example and edit it afterwards, if this is necessary. Xtremes supports the following data types.

- Xtremes Univariate Data; real data $x_1,...,x_n$ in any order, as presented above.
- Xtremes Grouped Data; pairs (t_j,n_j) of edges t_j and frequencies n_j of data in cells $[t_j,t_{j+1}]$.
- Xtremes Discrete Data; pairs (x_i,n_i) of reals x_i and integers n_i, if the data point x_i occurs n_i times.
- Xtremes Time Series; pairs (i,x_i) of integers i and reals x_i.
- Xtremes Censored Data; pairs (z_i,δ_i) of reals z_i and $\delta_i \in \{0,1\}$ showing whether the data point z_i is censored ($\delta_i = 0$) or uncensored ($\delta_i = 1$).
- Xtremes Multivariate Data; the data $(x_{i,1},...,x_{i,m})$ are stored using m entries on a line.

Data can be converted from one type into another by the option Data... Convert to. One can apply the UserFormula facility to perform transformations not covered by the menu system. More sophisticated conversions are accomplished by means of XPL programs.

3. Visualisation of Data

The Visualise menu contains options to display sample dfs, qfs, histograms, scatterplots, mean and median excess functions, among others. Kernel Density also provides options that reflects the data points at the right, left or both ends of the support. The bandwidth can be chosen by the user, an automatic selection (via cross-validation) is available. Multivariate data can be visualised in a 3-D plot.

4. Applying Estimators to the Active Data

The program has three different domains called SUM, MAX and POT. Each domain provides different distributions and estimators for the various distribution functions.

5. User Formula Facilities

A first extension to the menu system is provided by the UserFromula (UFO) facility. With UFO, the user can type in formulas that are used

- to evaluate expressions using a calculator
- to plot univariate or bivariate curves
- to generate data sets
- to transform existing data sets

The formulas are entered by using the notation of common programming languages. Operations that are too complicated for UFO may be handled by using the integrated programming language XPL.

6. The XPL Programming Language

To enhance the flexibility of the system beyond the possibilities of the UserFormula facility, it is supplemented by the integrated Pascal-like programming language XPL. One can use the implemented

- dialogue boxes
- plot windows and a so-called XPL window

when an XPL program is executed. One can also attach XPL programs to the menu bar, thus extending the menu system.

Appendix XIII: Dependency max_p versus min_s

List of figures:

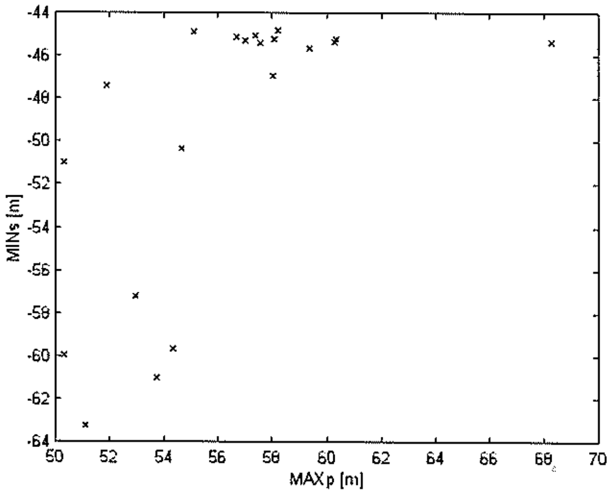


Figure 1 Plot of max_p versus min_s for condition 26

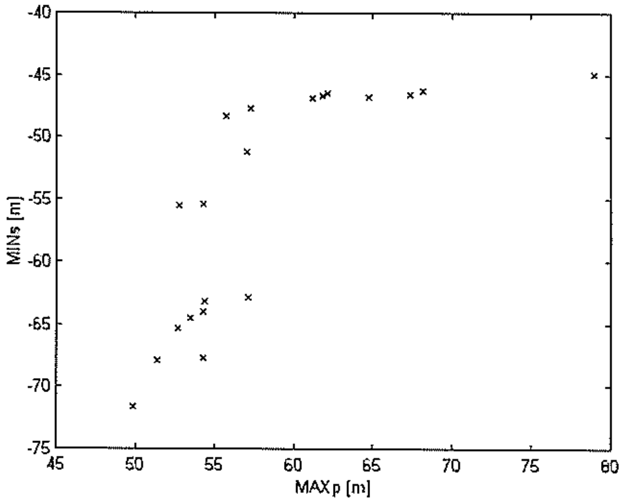


Figure 2 Plot of max_p versus min_s for condition 44

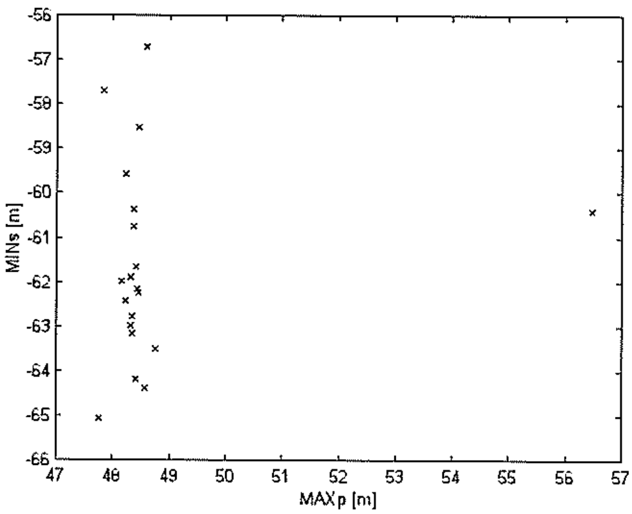


Figure 3 Plot of max_p versus min_s for condition 51

Appendix XIV: Fast time runs

List of tables:

Table 1 Fast time runs (set I)

													A	B
run	tide	hours HW	wind dir. [°]	wind vel. [m/sec]	swell dir. [°]	swell height [m]	F [-]	max. current velocity [m/sec]	water level [m]	max. port side [m]	min. port side [m]	swept path [m]	max_{max} [m]	A·1.17
1	average	+4	296	9.1	360	0.43	0.84106	0.21	0.23	36.1811	-33.4441	69.6252	36.1811	42.33189
2	spring	+3	184	1.1	348	0.99	1.0028	0.2	0.56	35.3197	-31.8691	67.1888	35.3197	41.32405
3	average	+2	337	6.4	345	0.06	0.804	0.34	0.62	42.199	-39.1191	81.3181	42.199	49.37283
4	average	+2	330	7.1	344	0.38	0.80178	0.34	0.62	42.838	-38.7384	81.5764	42.838	50.12046
5	average	+2	282	6.1	264	0.12	0.82898	0.35	0.62	42.9617	-39.7987	82.7604	42.9617	50.26519
6	average	+3	172	2.2	344	0.04	0.83829	0.16	0.52	34.021	-30.4019	64.4229	34.021	39.80457
7	spring	+1	19	4.2	334	0.16	0.98068	0.58	1.01	56.2852	-50.4854	106.7706	56.2852	65.85368
8	neap	+1	259	3.6	349	0.28	0.63494	0.38	0.71	46.8621	-41.0655	87.9276	46.8621	54.82866
9	neap	+2	346	6.1	238	0.17	0.60931	0.26	0.51	38.4097	-34.9449	73.3546	38.4097	44.93935
10	spring	+3	79	8.4	353	0.22	0.98017	0.19	0.56	35.2598	-31.4162	66.676	35.2598	41.25397
11	neap	+0	105	7	356	0.67	0.63474	0.56	0.85	58.523	-50.6572	109.1802	58.523	68.47191
12	spring	+2	90	6.1	358	0.18	0.99488	0.42	0.69	47.324	-42.9288	90.2528	47.324	55.36908
13	average	+3	240	3.3	2	0.36	0.84055	0.17	0.52	34.1321	-30.3808	64.5129	34.1321	39.93456
14	spring	+5	215	3.8	350	0.09	0.96834	0.51	0.08	51.2532	-45.3784	96.6316	51.2532	59.96624
15	average	+2	206	8.5	330	0.06	0.95852	0.4	0.62	47.6286	-42.2112	89.8398	47.6286	55.72546
16	spring	+2	340	5.1	342	0.37	0.97887	0.41	0.69	46.4738	-42.409	88.8828	46.4738	54.37435
17	spring	+5	272	2.5	313	0.15	0.99825	0.53	0.08	52.1789	-46.6904	98.8693	52.1789	61.04931
18	neap	+3	246	8.2	328	0.38	0.67154	0.13	0.43	32.3139	-29.2531	61.567	32.3139	37.80726
19	spring	+1	86	7.8	344	0.18	0.98835	0.59	1.01	57.1604	-51.0962	108.2566	57.1604	66.87767
20	average	+4	257	2.3	349	0.81	0.82636	0.21	0.23	36.0908	-32.766	68.8568	36.0908	42.22624
21	neap	+2	64	8	339	0.12	0.61063	0.26	0.51	38.8299	-35.0832	73.9131	38.8299	45.43098
22	neap	+4	214	7.8	338	0.15	0.54221	0.14	0.2	32.9737	-30.8073	63.781	32.9737	38.57923
23	spring	+4	259	8.5	333	0.1	0.9486	0.24	0.24	37.4718	-34.1368	71.6086	37.4718	43.84201
24	average	+5	328	14.3	343	0.57	0.91078	0.48	0.08	49.8199	-45.041	94.8609	49.8199	58.28928
25	average	+1	154	5.2	331	0.08	0.86503	0.52	0.89	53.2003	-48.5159	101.7162	53.2003	62.24435
26	average	+3	336	5.8	357	0.3	0.80866	0.16	0.52	33.4745	-30.1973	63.6718	33.4745	39.16517
27	average	+3	114	4.1	311	1.91	0.83552	0.16	0.52	33.6093	-31.2063	64.8156	33.6093	39.32288
28	average	+2	82	5.5	301	0.19	0.82404	0.35	0.62	43.1471	-39.6175	82.7646	43.1471	50.48211
29	average	+4	278	3.7	8	0.07	0.82922	0.21	0.23	36.2445	-33.9347	70.1792	36.2445	42.40607
30	average	+2	303	9.9	340	0.05	0.80513	0.34	0.62	42.6903	-38.7162	81.4065	42.6903	49.94765
31	spring	+3	65	4.9	312	0.28	0.98885	0.19	0.56	35.1801	-31.8865	67.0666	35.1801	41.16072
32	average	+5	283	9.6	339	0.18	0.83209	0.44	0.08	47.9403	-42.7124	90.6527	47.9403	56.09015

33	average	+3	105	3.7	311	0.31	0.83151	0.16	0.52	34.201	-30.2943	64.4953	34.201	40.01517
34	average	+1	75	6.7	304	0.2	0.81757	0.49	0.89	51.676	-46.9627	98.6387	51.676	60.46092
35	average	+1	81	8.4	308	0.31	0.81501	0.49	0.89	51.7234	-46.9341	98.6575	51.7234	60.51638
36	neap	+0	339	7.2	344	0.32	0.60426	0.53	0.85	55.0812	-48.523	103.6042	55.0812	64.445
37	average	+2	349	6.3	359	0.18	0.79971	0.34	0.62	43.3331	-38.9824	82.3155	43.3331	50.69973
38	spring	+3	204	3.4	360	0.07	1.0249	0.2	0.58	35.2479	-32.1672	67.4151	35.2479	41.24004
39	neap	-1	188	6.3	355	1.96	0.69433	0.49	0.37	55.0595	-48.0422	103.1017	55.0595	64.41962
40	average	+2	6	5.8	346	0.87	0.79775	0.33	0.62	42.8381	-38.8001	81.6382	42.8381	50.12058
41	average	+2	218	7.9	348	0.5	0.92299	0.39	0.62	46.3668	-41.6008	87.9676	46.3668	54.24916
42	average	-1	18	4.1	198	0.14	0.81492	0.58	0.47	60.4482	-52.132	112.5802	60.4482	70.72439
43	neap	+4	133	3.2	213	0.12	0.62263	0.16	0.2	33.9878	-31.0662	65.054	33.9878	39.76573
44	neap	+3	140	3.4	304	0.12	0.63814	0.13	0.43	32.5016	-28.3551	60.8567	32.5016	38.02687
45	average	+4	238	5.8	351	0.17	0.7899	0.2	0.23	35.6804	-32.4825	68.1629	35.6804	41.74607
46	neap	+1	196	0.7	304	0.66	0.63077	0.38	0.71	45.8865	-40.7618	86.6483	45.8865	53.68721
47	average	-1	356	4.7	336	0.04	0.81148	0.58	0.47	60.3528	-51.5755	111.9283	60.3528	70.61278
48	average	+1	141	2.7	338	0.79	0.83724	0.5	0.89	52.0925	-47.0064	99.0989	52.0925	60.94823
49	average	+5	67	8.1	346	0.1	0.84813	0.45	0.08	48.5558	-44.2585	92.8143	48.5558	56.81029
50	average	+2	227	10.1	337	0.6	0.9581	0.4	0.62	46.3442	-41.8437	88.1879	46.3442	54.22271
51	average	+4	65	9.4	334	0.06	0.85571	0.21	0.23	37.1818	-33.9742	71.156	37.1818	43.50271
52	spring	+5	355	6.7	333	0.11	1.0333	0.55	0.08	52.9438	-47.9801	100.9239	52.9438	61.94425
53	spring	+5	91	4.3	347	0.55	1.0017	0.53	0.08	52.3924	-46.2541	98.6465	52.3924	61.29911
54	average	+3	246	12.4	359	0.31	0.95662	0.19	0.52	34.6711	-31.6948	66.3659	34.6711	40.56519
55	neap	+2	89	6.3	332	0.51	0.62617	0.26	0.51	39.1717	-35.6317	74.8034	39.1717	45.83089
56	neap	+1	232	7.9	305	0.09	0.68435	0.41	0.71	47.6275	-42.3658	89.9933	47.6275	55.72418
57	neap	+5	323	3.5	342	0.1	0.63323	0.34	0.07	43.0125	-38.8786	81.8911	43.0125	50.32463
58	neap	+2	274	14.2	342	0.03	0.65022	0.27	0.51	38.0558	-35.5428	73.5986	38.0558	44.52529
59	average	+1	351	4	295	0.04	0.81781	0.49	0.89	51.2445	-46.1448	97.3893	51.2445	59.95607
60	neap	+4	184	7.4	22	0.24	0.52954	0.13	0.2	32.8169	-30.6049	63.4218	32.8169	38.39577
61	neap	+2	315	11.1	337	0.09	0.59369	0.25	0.51	37.6333	-34.7405	72.3738	37.6333	44.03096
62	neap	+1	212	7.9	345	0.56	0.70841	0.42	0.71	48.7053	-43.6358	92.3411	48.7053	56.9852
63	spring	+5	247	12.3	305	0.1	0.82654	0.44	0.08	47.4462	-42.8206	90.2668	47.4462	55.51205
64	spring	+1	57	5.6	143	0.09	0.98211	0.59	1.01	56.3129	-51.2484	107.5613	56.3129	65.88609
65	spring	+2	135	3.8	330	0.14	1.0144	0.43	0.69	47.4236	-43.0737	90.4973	47.4236	55.48561
66	average	+4	103	4.5	334	0.22	0.82801	0.21	0.23	36.3386	-32.9228	69.2614	36.3386	42.51616
67	average	+2	86	9	339	0.41	0.81735	0.34	0.62	44.3122	-38.9629	83.2751	44.3122	51.84527
68	neap	+2	80	10.8	230	0.23	0.61027	0.26	0.51	39.4433	-34.8563	74.2996	39.4433	46.14866
69	average	+5	170	4.3	260	0.19	0.79339	0.42	0.08	47.3322	-41.4726	88.8048	47.3322	55.37867

70	neap	-1	350	5.8	265	0.15	0.61005	0.43	0.37	52.02	-44.9705	96.9905	52.02	60.8634
71	spring	+4	305	8.5	338	0.31	1.0178	0.25	0.24	38.3917	-34.3033	72.695	38.3917	44.91829
72	average	+5	310	7.7	358	0.93	0.84493	0.45	0.08	48.3114	-43.6226	91.934	48.3114	56.52434
73	average	-1	358	12	341	0.38	0.7049	0.5	0.47	55.4877	-47.9975	103.4852	55.4877	64.92061
74	spring	+4	254	8.7	332	0.16	0.932	0.23	0.24	37.3057	-33.8862	71.1919	37.3057	43.64767
75	average	+1	116	4.1	17	0.26	0.83649	0.5	0.89	52.2429	-46.8035	99.0464	52.2429	61.12419
76	spring	+2	183	13.1	331	0.41	1.4105	0.59	0.69	54.6205	-50.0276	104.6481	54.6205	63.90599
77	spring	+3	206	5.5	342	0.1	1.0637	0.21	0.56	35.6242	-32.3672	67.9914	35.6242	41.68031
78	spring	-1	24	13.2	311	0.41	0.82119	0.58	0.53	59.9219	-51.3409	111.2628	59.9219	70.10862
79	spring	+2	117	6.5	331	0.27	1.0207	0.43	0.69	47.9666	-43.7306	91.6972	47.9666	56.12092
80	spring	+4	113	6.2	336	0.41	0.98339	0.24	0.24	38.2769	-35.4195	73.6964	38.2769	44.78397
81	spring	+3	163	5.7	358	0.14	1.0599	0.21	0.56	35.6969	-32.5242	68.2211	35.6969	41.76537
82	spring	+1	104	5.2	286	0.1	1.003	0.6	1.01	56.9933	-51.6343	108.6276	56.9933	66.68216
83	neap	+3	196	6.2	330	0.1	0.68845	0.14	0.43	32.9175	-29.1016	62.0191	32.9175	38.51348
84	neap	-1	252	3.3	346	0.97	0.63573	0.45	0.37	52.9497	-45.2374	98.1871	52.9497	61.95115
85	average	+4	109	3.5	312	0.32	0.82681	0.21	0.23	36.3231	-32.5253	68.8484	36.3231	42.49803
86	average	-1	28	1.9	13	3.09	0.82709	0.59	0.47	61.3869	-52.1069	113.4938	61.3869	71.82267
87	average	+3	86	9.3	324	0.01	0.81703	0.16	0.52	34.4291	-30.0241	64.4532	34.4291	40.28205
88	spring	+3	356	2.2	337	0.94	0.99511	0.2	0.56	35.2878	-32.0981	67.3859	35.2878	41.28673
89	average	+3	329	7	253	0.25	0.80313	0.16	0.52	33.4797	-29.8935	63.3732	33.4797	39.17125
90	neap	+2	209	7.2	19	0.02	0.69778	0.29	0.51	41.2063	-37.1613	78.3676	41.2063	48.21137
91	neap	+1	87	5.9	357	0.07	0.62632	0.37	0.71	45.5321	-41.6458	87.1779	45.5321	53.27256
92	average	+3	130	4.2	331	0.25	0.84283	0.17	0.52	34.1386	-30.2849	64.4235	34.1386	39.94216
93	average	+5	324	0.6	341	2.36	0.83014	0.44	0.08	47.9336	-42.6624	90.596	47.9336	56.08231
94	neap	-1	351	7	333	0.17	0.60097	0.43	0.37	51.1895	-44.7089	95.8984	51.1895	59.89172
95	spring	+1	13	4.6	358	0.32	0.97505	0.58	1.01	55.9862	-50.3985	106.3847	55.9862	65.50385
96	average	+4	230	10.6	338	0.21	0.67106	0.17	0.23	33.981	-31.4074	65.3884	33.981	39.75777
97	average	+5	325	8.4	335	0.52	0.85641	0.45	0.08	48.7933	-42.967	91.7603	48.7933	57.08816
98	average	+3	344	5	305	0.07	0.81242	0.16	0.52	33.3447	-30.3628	63.7075	33.3447	39.0133
99	average	+5	297	10.3	220	0.14	0.84462	0.45	0.08	47.8237	-42.5663	90.39	47.8237	55.95373
100	average	-1	17	5.9	355	0.09	0.79778	0.57	0.47	59.396	-51.1581	110.5541	59.396	69.49332

Table 2 Fast time runs (set I & 2)

													A	B
run	tide	hours HW	wind dir. [°]	wind vel. [m/sec]	swell dir. [°]	swell height [m]	F [-]	max. current velocity [m/sec]	water level [m]	max. port side [m]	min. port side [m]	swept path [m]	max_{max} [m]	A·1.17
1	neap	-4	224	9.3	28	0.04	0.5246	0.2	-0.78	37.4162	-32.6206	70.0368	37.4162	43.77695
2	average	-1	192	7.8	333	0.79	0.957	0.68	0.47	66.4623	-56.3355	122.7978	66.4623	77.76089
3	neap	+2	101	6.8	350	0.36	0.6308	0.26	0.51	39.393	-35.7115	75.1045	39.393	46.08981
4	average	+1	331	3.8	345	0.45	0.8217	0.49	0.89	51.6205	-46.8012	98.4217	51.6205	60.39599
5	neap	+6	229	10.1	333	0.23	0.5165	0.29	-0.08	40.5637	-35.9442	76.5079	40.5637	47.45953
6	average	+1	173	7.2	351	0.4	0.9203	0.55	0.89	55.404	-49.4107	104.8147	55.404	64.82268
7	neap	+3	122	1.5	337	0.07	0.6309	0.12	0.43	32.6092	-28.58	61.1892	32.6092	38.15276
8	average	0	332	0.9	355	0.02	0.8295	0.73	1.1	66.3168	-58.212	124.5288	66.3168	77.59066
9	spring	+2	195	14.2	359	0.21	1.4976	0.63	0.69	59.0928	-53.2447	112.3375	59.0928	69.13858
10	average	+5	118	1.8	185	0.05	0.8284	0.44	0.08	48.2746	-42.4025	90.6771	48.2746	56.48128
11	spring	+6	225	10.8	6	0.3	0.7813	0.45	-0.09	49.0181	-41.5212	90.5393	49.0181	57.35118
12	average	-1	230	5.3	13	0.23	0.8633	0.61	0.47	62.5594	-53.7679	116.3273	62.5594	73.1945
13	spring	+3	227	0.6	3	0.05	1.0005	0.2	0.56	34.8481	-32.2143	67.0624	34.8481	40.77228
14	neap	-6	48	6	243	0.56	0.6417	0.37	-0.35	45.6044	-39.6333	85.2377	45.6044	53.35715
15	spring	+3	98	5.3	342	0.06	0.9993	0.2	0.56	35.4974	-32.0433	67.5407	35.4974	41.53196
16	average	-1	326	12	320	0.09	0.7555	0.54	0.47	57.1294	-50.1407	107.2701	57.1294	66.8414
17	spring	-6	149	3.9	356	0.37	0.9735	0.56	-0.39	53.5808	-48.9431	102.5239	53.5808	62.68954
18	neap	+2	234	9.9	326	0.07	0.712	0.3	0.51	41.4093	-36.7388	78.1481	41.4093	48.44888
19	average	+1	252	3	352	0.24	0.836	0.5	0.89	52.0536	-46.9385	98.9921	52.0536	60.90271
20	average	-1	168	4.9	306	0.06	0.8693	0.62	0.47	63.1492	-54.1445	117.2937	63.1492	73.88456
21	spring	-5	248	5	344	0.48	0.9726	0.48	-0.89	51.1628	-46.104	97.2668	51.1628	59.86048
22	average	+5	301	8	330	0.1	0.8413	0.45	0.08	47.981	-43.1521	91.1331	47.981	56.13777
23	neap	-2	253	7	286	0.09	0.6541	0.07	-0.37	32.7072	-26.8834	59.5906	32.7072	38.26742
24	spring	-4	176	4.3	318	0.07	0.9527	0.37	-0.96	46.3126	-41.43	87.7426	46.3126	54.18574
25	neap	+4	251	6.1	358	0.07	0.6069	0.15	0.2	34.0064	-30.5923	64.5987	34.0064	39.78749
26	spring	+3	354	2.2	263	0.6	0.9951	0.2	0.56	34.9984	-31.7238	66.7222	34.9984	40.94813
27	average	+5	194	5.1	18	0.07	0.7654	0.41	0.08	46.2486	-41.9931	88.2417	46.2486	54.11086
28	neap	+4	171	5.8	341	0.19	0.5782	0.14	0.2	33.2931	-30.5867	63.8798	33.2931	38.95293
29	neap	-3	283	5.8	358	0.22	0.6306	0.13	-0.57	34.7	-29.8857	64.5857	34.7	40.599
30	neap	-5	262	13.2	330	0.07	0.5617	0.28	-0.76	41.0088	-35.6104	76.6192	41.0088	47.9803
31	average	+2	229	6.3	353	0.17	0.8782	0.37	0.62	44.8841	-40.7529	85.637	44.8841	52.5144
32	average	+4	340	8.5	300	0.09	0.8661	0.22	0.23	36.2663	-34.1232	70.3895	36.2663	42.43157

33	neap	+3	80	8.4	337	0.14	0.6184	0.12	0.43	33.1471	-28.6093	61.7564	33.1471	38.78211
34	average	-4	320	5.2	347	1.84	0.8391	0.32	-0.91	44.0863	-39.0096	83.0959	44.0863	51.58097
35	neap	+4	125	1.4	244	0.28	0.6289	0.16	0.2	33.9401	-30.8565	64.7966	33.9401	39.70992
36	average	+6	82	6.6	350	0.08	0.8363	0.48	-0.09	49.9991	-44.9531	94.9522	49.9991	58.49895
37	average	+4	329	5.3	311	0.16	0.8412	0.21	0.23	36.7184	-32.7111	69.4295	36.7184	42.96053
38	spring	-3	2	4.8	16	0.64	1.0192	0.21	-0.73	39.5265	-34.5958	74.1223	39.5265	46.24601
39	neap	-6	311	0.9	341	0.1	0.6302	0.36	-0.35	44.9303	-39.3079	84.2382	44.9303	52.56845
40	spring	-3	142	5	349	0.11	0.9636	0.2	-0.73	38.7603	-33.3694	72.1297	38.7603	45.34955
41	average	+4	298	15.4	352	1.26	0.8659	0.22	0.23	36.22	-33.1662	69.3862	36.22	42.3774
42	spring	+6	43	5.8	352	0.09	1.0194	0.58	-0.09	54.8447	-49.0444	103.8891	54.8447	64.1683
43	neap	+6	294	18.1	286	0.06	0.659	0.38	-0.08	45.2694	-39.6766	84.946	45.2694	52.9652
44	spring	-6	246	10.9	360	0.38	0.8597	0.49	-0.39	51.1826	-44.2994	95.482	51.1826	59.88364
45	average	-1	268	11.5	312	0.37	0.8686	0.62	0.47	62.6543	-53.7967	116.451	62.6543	73.30553
46	spring	-2	98	1	288	1.78	1	0.1	-0.5	36.2397	-29.5795	65.8192	36.2397	42.40045
47	average	-2	234	11.2	346	0.99	0.9672	0.1	-0.46	36.1949	-28.6904	64.8853	36.1949	42.34803
48	neap	+1	105	3.5	348	0.26	0.6312	0.38	0.71	46.3845	-41.4806	87.8651	46.3845	54.26987
49	neap	-1	324	3.8	25	0.04	0.6248	0.44	0.37	52.4876	-45.5555	98.0431	52.4876	61.41049
50	spring	+2	285	3.5	337	0.71	0.9991	0.42	0.69	47.2667	-43.0857	90.3524	47.2667	55.30204
51	average	-5	111	3.2	3	0.14	0.8269	0.41	-0.86	48.2317	-41.7503	89.982	48.2317	56.43109
52	spring	+2	190	9.2	359	0.24	1.2183	0.51	0.69	51.0206	-46.9228	97.9434	51.0206	59.6941
53	neap	-3	312	10.4	341	0.2	0.652	0.14	-0.57	35.3065	-29.7216	65.0281	35.3065	41.30861
54	spring	-4	242	0.2	341	0.19	1	0.39	-0.96	47.4921	-42.1283	89.6204	47.4921	55.56576
55	average	-6	232	11.9	351	0.19	0.6365	0.36	-0.39	44.8692	-38.8448	83.714	44.8692	52.49696
56	average	-6	234	3.8	333	0.13	0.8105	0.46	-0.39	49.6619	-43.3458	93.0077	49.6619	58.10442
57	spring	+6	219	11.6	348	0.4	0.7219	0.41	-0.09	47.0733	-40.1844	87.2577	47.0733	55.07576
58	average	-4	245	6.9	1	0.04	0.7824	0.3	-0.91	43.1547	-37.2033	80.358	43.1547	50.491
59	neap	+4	259	5.1	338	0.09	0.6184	0.15	0.2	33.6508	-31.0834	64.7342	33.6508	39.37144
60	average	+3	221	17.7	341	0.26	1.274	0.25	0.52	38.5555	-35.0209	73.5764	38.5555	45.10994
61	average	-5	108	3.1	348	0.05	0.8279	0.41	-0.86	47.7683	-42.482	90.2503	47.7683	55.88891
62	neap	+4	153	8.6	341	0.06	0.5455	0.14	0.2	33.3928	-30.6776	64.0704	33.3928	39.06958
63	spring	-2	118	6.7	316	0.19	1.0239	0.1	-0.5	37.3374	-29.8714	67.2088	37.3374	43.68476
64	average	-4	330	5.4	340	0.17	0.8422	0.33	-0.91	44.2932	-39.1616	83.4548	44.2932	51.82304
65	average	+4	63	10.9	343	0.08	0.8671	0.22	0.23	37.1942	-34.1995	71.3937	37.1942	43.51721
66	neap	-6	237	8.3	322	0.15	0.5664	0.32	-0.35	42.9037	-37.9716	80.8753	42.9037	50.19733
67	spring	-1	283	9.1	353	0.09	0.9961	0.71	0.53	68.1273	-58.1287	126.256	68.1273	79.70894
68	spring	+6	227	9.3	354	0.06	0.8406	0.48	-0.09	50.0335	-43.2933	93.3268	50.0335	58.5392
69	average	0	286	2.1	317	0.22	0.8297	0.73	1.1	66.5586	-58.1648	124.7234	66.5586	77.87356

70	neap	+1	219	7.5	336	0.28	0.6916	0.41	0.71	47.6017	-43.0144	90.6161	47.6017	55.69399
71	spring	+3	175	4.3	23	0.82	1.0398	0.2	0.56	36.3068	-31.9832	68.29	36.3068	42.47896
72	neap	-6	314	14.5	16	0.47	0.6751	0.39	-0.35	45.4849	-40.4195	85.9044	45.4849	53.21733
73	neap	-5	347	2.7	333	0.33	0.633	0.31	-0.76	43.3575	-37.1038	80.4613	43.3575	50.72828
74	neap	0	62	3.7	1	1.33	0.6258	0.55	0.85	56.7092	-50.1395	106.8487	56.7092	66.34976
75	average	-2	262	0.9	293	0.32	0.8303	0.08	-0.46	34.3092	-28.0427	62.3519	34.3092	40.14176
76	spring	+6	69	1.8	336	0.09	1.001	0.57	-0.09	54.331	-48.0835	102.4145	54.331	63.56727
77	average	+4	306	7.6	333	0.64	0.8428	0.21	0.23	36.474	-33.8464	70.3204	36.474	42.67458
78	average	-1	231	2.8	305	0.09	0.839	0.6	0.47	61.3721	-52.9377	114.3098	61.3721	71.80536
79	average	-2	214	8.7	329	0.15	0.952	0.09	-0.46	35.8203	-29.3306	65.1509	35.8203	41.90975
80	average	+1	322	5.6	333	0.09	0.8154	0.49	0.89	50.797	-45.8996	96.6966	50.797	59.43249
81	average	-3	311	2.2	332	0.23	0.8313	0.17	-0.68	37.3776	-31.7567	69.1343	37.3776	43.73179
82	average	+1	189	13.4	338	0.27	1.2109	0.72	0.89	63.1806	-57.5467	120.7273	63.1806	73.9213
83	average	+6	183	10.3	268	0.03	0.5799	0.33	-0.09	42.8923	-37.3505	80.2428	42.8923	50.18399
84	neap	+6	223	12.4	331	0.13	0.4389	0.25	-0.08	39.2222	-33.3404	72.5626	39.2222	45.88997
85	spring	+6	217	7.7	352	0.16	0.8715	0.5	-0.09	50.7508	-44.2752	95.026	50.7508	59.37844
86	average	+4	214	12.8	330	0.38	0.5192	0.13	0.23	32.1922	-29.2166	61.4088	32.1922	37.66487
87	average	-2	213	6.8	340	0.43	0.9031	0.09	-0.46	35.2141	-28.4828	63.6969	35.2141	41.2005
88	neap	-3	75	5.2	336	0.6	0.6343	0.13	-0.57	35.0198	-29.4624	64.4822	35.0198	40.97317
89	average	+1	236	8.4	282	0.56	0.9055	0.54	0.89	54.8993	-48.6916	103.5909	54.8993	64.23218
90	neap	0	153	9.8	304	0.01	0.7212	0.63	0.85	63.2973	-54.6476	117.9449	63.2973	74.05784
91	spring	+6	83	6.8	307	0.07	1.0077	0.57	-0.09	54.4557	-49.0753	103.531	54.4557	63.71317
92	average	-5	324	5.7	352	0.07	0.8419	0.42	-0.86	47.6242	-43.2346	90.8588	47.6242	55.72031
93	spring	+5	218	11.2	297	0.14	0.7318	0.39	0.08	45.4299	-39.988	85.4179	45.4299	53.15298
94	neap	-1	134	3.4	321	0.09	0.6372	0.45	0.37	53.1682	-46.1756	99.3438	53.1682	62.20679
95	spring	-3	219	4	263	0.17	0.9658	0.2	-0.73	38.3092	-34.0051	72.3143	38.3092	44.82176
96	average	-4	147	2.9	342	0.25	0.8188	0.32	-0.91	43.7781	-38.4236	82.2017	43.7781	51.22038
97	spring	-5	80	10.2	338	0.2	1.0208	0.51	-0.89	52.2772	-48.5274	100.8046	52.2772	61.16432
98	neap	+5	349	11.4	177	0.19	0.6863	0.36	0.07	44.1675	-40.1639	84.3314	44.1675	51.67598
99	average	+4	56	6.5	329	0.04	0.8454	0.21	0.23	36.6764	-33.4326	70.109	36.6764	42.91139
100	average	+1	298	6.8	17	0.09	0.821	0.49	0.89	50.7386	-46.0121	96.7507	50.7386	59.36416

Appendix XV: Matlab® programs

Table of contents:

List of figures:

1. Generate wind-rose

1.1 Insert data from ASCII into Matlab

Below the program is given which transforms the data from the wind files into a matrix in Matlab.

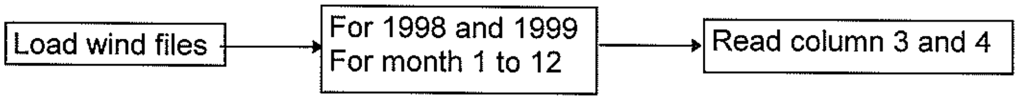


Figure 1 Flow diagram Insert_wind

The file can be found in **D:\Matlab\Insert_wind (CD ROM)**

```
% Insert_wind
function [outsn,outri]=
D:\Input_files\Wind_files\leeswind(jr1,jr2,mxmnd,sbf,loc);
% [outsn,outri] = leeswind(98,98,12,'wio5','ymd');
% [outsn,outri] = leeswind(99,99,11,'wio5','ymd');
loc=('ymd');
sbf=('wio5');
extensie=['.' loc];
outsn=[];
outri=[];
jr1=98;
jr2=99;
mxmnd=12;
for n = jr1:jr2
   for j = 1:mxmnd
      if j<10
         j
         k=0;
         mnd=[int2str(k),int2str(j)];
      else
         j
         mnd=int2str(j);
      end
      variabel=[int2str(n),mnd];
      filename=[variabel, sbf, extensie];
      eval(['load ', filename])
      filecat=['X',variabel, sbf];
      eval(['outsn= [ outsn ;' filecat '(:,3)];'']);
      eval(['outri= [ outri ;' filecat '(:,4)];'']);
   end
end
```

1.2 Generate rose

The program given below generates the wind rose, the program first determines in which wind velocity class the observation fits, subsequently the wind angle class of the observation is determined. Only the first two of a total of 10 wind velocity classes are given.

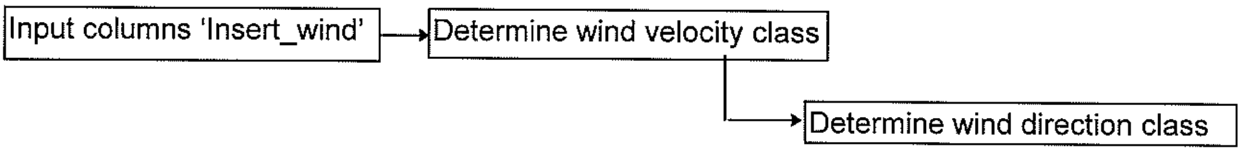


Figure 2 Flow diagram Windrose

The file can be found in **D:\Matlab\Windrose (CD ROM)**

```
%Windrose
a1..a12=0;
b1..b12=0;
c1..c12=0;
..
..

C=[];
for n=1:4464
   if A(n,1)<=2.5
         if A(n,2)>0 & A(n,2)<=30
            a1=a1+1;
            C(1,1)=a1;
         end
         if A(n,2)>30 & A(n,2)<=60
            a2=a2+1;
            C(1,2)=a2;
         end
         if A(n,2)>60 & A(n,2)<=90
            a3=a3+1;
            C(1,3)=a3;
         end
         if A(n,2)>90 & A(n,2)<=120
            a4=a4+1;
            C(1,4)=a4;
         end
         if A(n,2)>120 & A(n,2)<=150
            a5=a5+1;
            C(1,5)=a5;
         end
         if A(n,2)>150 & A(n,2)<=180
            a6=a6+1;
            C(1,6)=a6;
         end
         if A(n,2)>180 & A(n,2)<=210
            a7=a7+1;
            C(1,7)=a7;
         end
         if A(n,2)>210 & A(n,2)<=240
            a8=a8+1;
            C(1,8)=a8;
         end
         if A(n,2)>240 & A(n,2)<=270
            a9=a9+1;
            C(1,9)=a9;
         end
           if A(n,2)>270 & A(n,2)<=300
            a10=a10+1;
            C(1,10)=a10;
         end
```

```
        if A(n,2)>300 & A(n,2)<=330
           a11=a11+1;
           C(1,11)=a11;
        end
        if A(n,2)>330 & A(n,2)<=360
           a12=a12+1;
           C(1,12)=a12;
        end
  end
  if A(n,1)>2.5 & A(n,1)<=5
        if A(n,2)>0 & A(n,2)<=30
           b1=b1+1;
           C(2,1)=b1;
        end
        if A(n,2)>30 & A(n,2)<=60
           b2=b2+1;
           C(2,2)=b2;
        end
        if A(n,2)>60 & A(n,2)<=90
           b3=b3+1;
           C(2,3)=b3;
        end
        if A(n,2)>90 & A(n,2)<=120
           b4=b4+1;
           C(2,4)=b4;
        end
        if A(n,2)>120 & A(n,2)<=150
           b5=b5+1;
           C(2,5)=b5;
        end
        if A(n,2)>150 & A(n,2)<=180
           b6=b6+1;
           C(2,6)=b6;
        end
        if A(n,2)>180 & A(n,2)<=210
           b7=b7+1;
           C(2,7)=b7;
        end
        if A(n,2)>210 & A(n,2)<=240
           b8=b8+1;
           C(2,8)=b8;
        end
        if A(n,2)>240 & A(n,2)<=270
           b9=b9+1;
           C(2,9)=b9;
        end
          if A(n,2)>270 & A(n,2)<=300
           b10=b10+1;
           C(2,10)=b10;
        end
        if A(n,2)>300 & A(n,2)<=330
           b11=b11+1;
           C(2,11)=b11;
        end
        if A(n,2)>330 & A(n,2)<=360
           b12=b12+1;
           C(2,12)=b12;
        end
```

```
    end
    ...


end
C
```

2. Generate random natural condition

2.1 Generate

Below the program is given which generates wind-, current- and swell conditions.

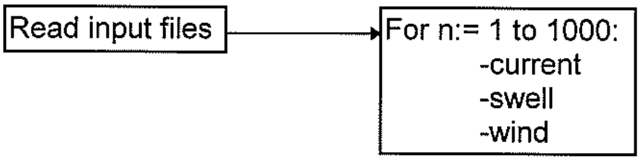


Figure 3 Flow diagram Generate

The file can be found in **D:\Matlab\Generate (CD ROM)**

```
%Generate
clc
clear
A=[];

%water levels astro spring tide, from -6 hours to + 6 hours high
tide, x=97200 y=97900
Wa=[-0.3891; -0.8904; -0.9646; -0.7342; -0.5048; 0.5341; 1.2828;
1.0134; 0.6880; 0.5607; 0.2441; 0.0777; -0.0920];

%Wind
Wf=[];
Wf(1,1:56)=dlmread('W1f', ';');
Wf(4,1:45)=dlmread('W4f', ';');
Wf(10,1:86)=dlmread('W10f', ';');
Wf(12,1:64)=dlmread('W12f', ';');

Ws=[];
Ws(1,1:56)=dlmread('W1s', ';');
Ws(4,1:45)=dlmread('W4s', ';');
Ws(10,1:86)=dlmread('W10s', ';');
Ws(12,1:64)=dlmread('W12s', ';');

W=[0 0.04429 0.08814 0.17552 0.23737 0.29072 0.37375 0.47604 0.66195
0.77662 0.86292 0.93191 1];
angw=[0 30 60 90 120 150 180 210 240 270 300 330 360];

%Swell
Sf=[];
Sf(1,1:161)=dlmread('S1f', ';');
Sf(8,1:230)=dlmread('S8f', ';');
Sf(9,1:254)=dlmread('S9f', ';');
Sf(10,1:212)=dlmread('S10f', ';');
Sf(11,1:231)=dlmread('S11f', ';');
Sf(12,1:250)=dlmread('S12f', ';');
```

```
Ss=[];
Ss(1,1:161)=dlmread('S1s', ';');
Ss(8,1:230)=dlmread('S8s', ';');
Ss(9,1:254)=dlmread('S9s', ';');
Ss(10,1:212)=dlmread('S10s', ';');
Ss(11,1:231)=dlmread('S11s', ';');
Ss(12,1:250)=dlmread('S12s', ';');

S=[0 0.06941 0.0829 0.08705 0.08995 0.0926 0.09495 0.1011 0.13379
0.17901 0.22374 0.3899 1];
angs=[0 30 60 90 120 150 180 210 240 270 300 330 360];

for n=1:1000
   current
   swell
   wind
end
```

2.2 Current

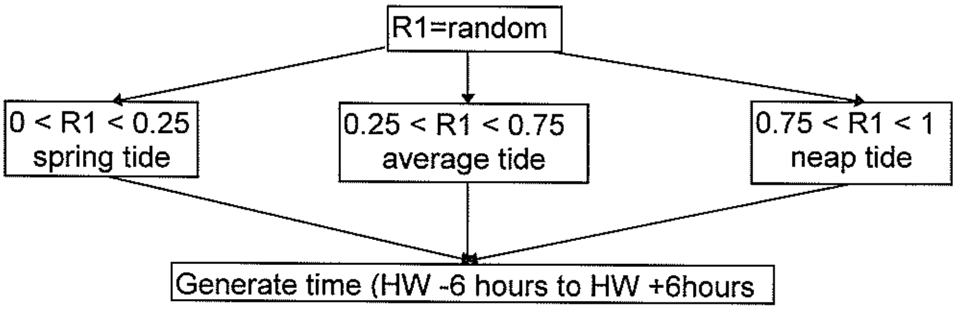


Figure 4 Flow diagram Current

The file can be found in **D:\Matlab\Current (CD ROM)**

```
%Current
r1=rand(1);
if r1>0 & r1<=0.25
   A(n,7)=1;
   %A(n,1)=['spring tide'];
end
if r1>0.25 & r1<=0.75
   A(n,7)=2;
   %A(n,1)=['average    '];
end
if r1>0.75 & r1<=1
   A(n,7)=3;
   %A(n,1)=['neap tide  '];
end

r2=rand(1);
if r2>0 & r2<=0.0769
   A(n,8)=-6;
   %A(n,2)=['-6 hours '];
end
if r2>0.0769 & r2<=0.1538
   A(n,8)=-5;
   %A(n,2)=['-5 hours '];
```

```
end
if r2>0.1538 & r2<=0.2307
   A(n,8)=-4;
   %A(n,2)=['-4 hours '];
end
if r2>0.2307 & r2<=0.3076
   A(n,8)=-3;
   %A(n,2)=['-3 hours '];
end
if r2>0.3076 & r2<=0.3845
   A(n,8)=-2;
   %A(n,2)=['-2 hours '];
end
if r2>0.3845 & r2<=0.4614
   A(n,8)=-1;
   %A(n,2)=['-1 hour  '];
end
if r2>0.4614 & r2<=0.5386
   A(n,8)=0;
   %A(n,2)=['high tide'];
end
if r2>0.5386 & r2<=0.6155
   A(n,8)=1;
   %A(n,2)=['+1 hour  '];
end
if r2>0.6155 & r2<=0.6924
   A(n,8)=2;
   %A(n,2)=['+2 hours '];
end
if r2>0.6924 & r2<=0.7693
   A(n,8)=3;
   %A(n,2)=['+3 hours '];
end
if r2>0.7693 & r2<=0.8462
   A(n,8)=4;
   %A(n,2)=['+4 hours '];
end
if r2>0.8462 & r2<=0.9231
   A(n,8)=5;
   %A(n,2)=['+5 hours '];
end
if r2>0.9231 & r2<=1
   A(n,8)=6;
   %A(n,2)=['+6 hours '];
end
```

2.3 Swell

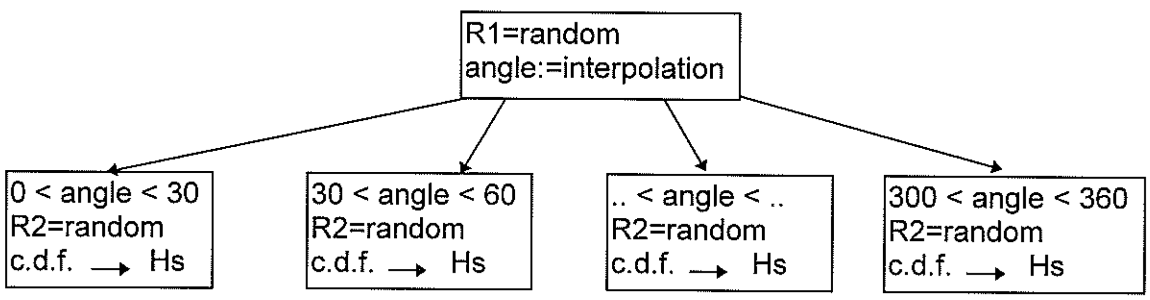


Figure 5 Flow diagram Swell

The file can be found in **D:\Matlab\Swell (CD ROM)**

```
%swell
rsa=rand(1);
A(n,5)=interp1(S,angs,rsa);
if A(n,5)>0 & A(n,5)<=30
   rg=rand(1);
   A(n,6)=interp1(Sf(1,1:161),Ss(1,1:161),rg);
end
if A(n,5)>30 & A(n,5)<=60
   rg=rand(1);
   A(n,6)=rg/5;
end
if A(n,5)>60 & A(n,5)<=90
   rg=rand(1);
   A(n,6)=rg/5;
end
if A(n,5)>90 & A(n,5)<=120
   rg=rand(1);
   A(n,6)=rg/5;
end
if A(n,5)>120 & A(n,5)<=150
   rg=rand(1);
   A(n,6)=rg/5;
end
if A(n,5)>150 & A(n,5)<=180
   rg=rand(1);
   A(n,6)=rg/5;
end
if A(n,5)>180 & A(n,5)<=210
   rg=rand(1);
   A(n,6)=rg/5;
end
if A(n,5)>210 & A(n,5)<=240
   rg=rand(1);
   A(n,6)=interp1(Sf(8,1:230),Ss(8,1:230),rg);
end
if A(n,5)>240 & A(n,5)<=270
   rg=rand(1);
   A(n,6)=interp1(Sf(9,1:254),Ss(9,1:254),rg);
end
if A(n,5)>270 & A(n,5)<=300
   rg=rand(1);
   A(n,6)=interp1(Sf(10,1:212),Ss(10,1:212),rg);
end
if A(n,5)>300 & A(n,5)<=330
   rg=rand(1);
   A(n,6)=interp1(Sf(11,1:231),Ss(11,1:231),rg);
end
if A(n,5)>330 & A(n,5)<=360
   rg=rand(1);
   A(n,6)=interp1(Sf(12,1:250),Ss(12,1:250),rg);
end
```

2.4 Wind

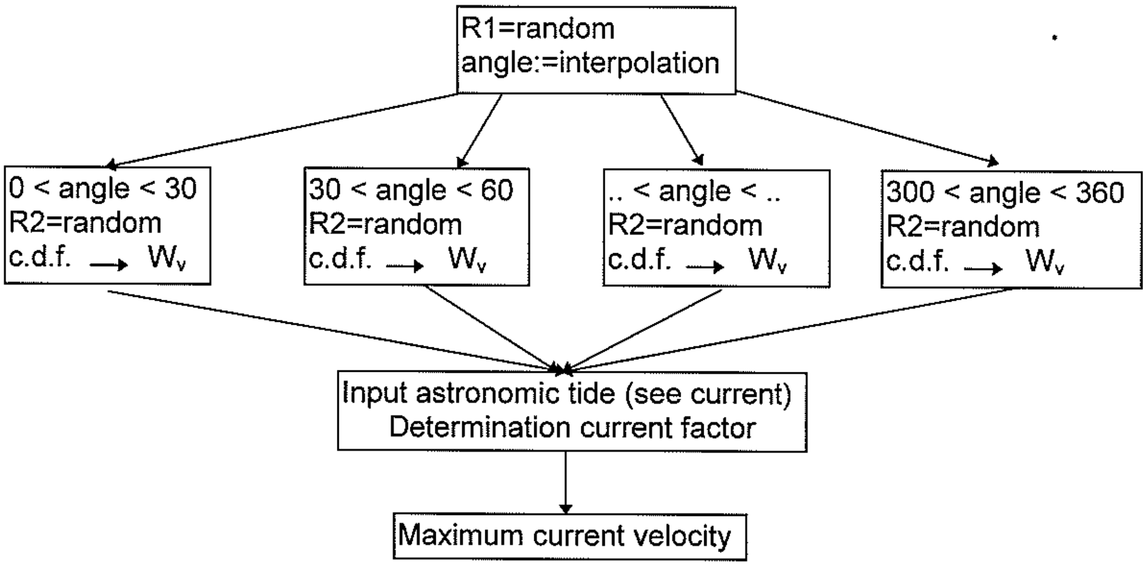


Figure 6 Flow diagram Wind

The file can be found in **D:\Matlab\Wind (CD ROM)**

```
%Wind
rwa=rand(1);
A(n,3)=interp1(W,angw,rwa);
if A(n,3)>0 & A(n,3)<=30
   rws=rand(1);
   A(n,4)=interp1(Wf(1,1:56),Ws(1,1:56),rws);
end
if A(n,3)>30 & A(n,3)<=60
   %Weibull
   a=2.26;
   b=6.13;
   rws=rand(1);
   A(n,4)=(-log10(1-rws)/log10(exp(1)))^(1/a)*b;
end
if A(n,3)>60 & A(n,3)<=90
   %Logistic
   a=6.65;
   b=1.42;
   rws=rand(1);
   A(n,4)=-b*(log10(1/rws-1)/log10(exp(1)))+a;
end
if A(n,3)>90 & A(n,3)<=120
   rws=rand(1);
   A(n,4)=interp1(Wf(4,1:45),Ws(4,1:45),rws);
end
if A(n,3)>120 & A(n,3)<=150
   %Logistic
   a=3.71;
   b=1.14;
   rws=rand(1);
   A(n,4)=-b*(log10(1/rws-1)/log10(exp(1)))+a;
end
if A(n,3)>150 & A(n,3)<=180
```

```
    %Logistic
    a=5.41;
    b=1.33;
    rws=rand(1);
    A(n,4)=-b*(log10(1/rws-1)/log10(exp(1)))+a;
end
if A(n,3)>180 & A(n,3)<=210
    %Logistic
    a=7.95;
    b=2.44;
    rws=rand(1);
    A(n,4)=-b*(log10(1/rws-1)/log10(exp(1)))+a;
end
if A(n,3)>210 & A(n,3)<=240
    %Logistic
    a=9.25;
    b=2.01;
    rws=rand(1);
    A(n,4)=-b*(log10(1/rws-1)/log10(exp(1)))+a;
end
if A(n,3)>240 & A(n,3)<=270
    %Logistic
    a=7.72;
    b=2.39;
    rws=rand(1);
    A(n,4)=-b*(log10(1/rws-1)/log10(exp(1)))+a;
end
if A(n,3)>270 & A(n,3)<=300
    rws=rand(1);
    A(n,4)=interp1(Wf(10,1:86),Ws(10,1:86),rws);
end
if A(n,3)>300 & A(n,3)<=330
    %Weibull
    a=2.09;
    b=8.74;
    rws=rand(1);
    A(n,4)=(-log10(1-rws)/log10(exp(1)))^(1/a)*b;
end
if A(n,3)>330 & A(n,3)<=360
    rws=rand(1);
    A(n,4)=interp1(Wf(12,1:64),Ws(12,1:64),rws);
end

%determination current factor by wind
%flood (factor according to flood astro)
if A(n,8)>=-2 & A(n,8)<=3
    %South
    if A(n,3)>100 & A(n,3)<=190
        A(n,9)=0.0026*(A(n,3)-100)/90;         %a
    end
    if A(n,3)>190 & A(n,3)<=280
        A(n,9)=0.0026*(1-((A(n,3)-190)/90));   %a
    end
    %North
    if A(n,3)>0 & A(n,3)<=10
        A(n,9)=-0.0012*(A(n,3)+360-280)/90;    %a
    end
    if A(n,3)>10 & A(n,3)<=100
```

```
      A(n,9)=-0.0012*(1-((A(n,3)-10)/90));  %a
   end
   if A(n,3)>280 & A(n,3)<=360
      A(n,9)=-0.0012*(A(n,3)-280)/90;       %a
   end
else %ebb (factor according to ebb astro)
   %South
   if A(n,3)>100 & A(n,3)<=190
      A(n,9)=-0.0031*(A(n,3)-100)/90;       %a
   end
   if A(n,3)>190 & A(n,3)<=280
      A(n,9)=-0.0031*(1-((A(n,3)-190)/90)); %a
   end
   %North
   if A(n,3)>0 & A(n,3)<=10
      A(n,9)=0.0009*(A(n,3)+360-280)/90;    %a
   end
   if A(n,3)>10 & A(n,3)<=100
      A(n,9)=0.0009*(1-((A(n,3)-10)/90));   %a
   end
   if A(n,3)>280 & A(n,3)<=360
      A(n,9)=0.0009*(A(n,3)-280)/90;        %a
   end
end

%determination current factor by tide
p=A(n,8)+7;
switch A(n,7)
   case 1          %spring tide
      A(n,10)=1;
      A(n,14)=Wa(p);                                  %water level
   case 2          %average tide
      A(n,10)=0.83;
      A(n,14)=Wa(p)*(0.86+abs(A(n,8)/6)*0.13); %water level
   otherwise       %neap tide
      A(n,10)=0.63;
      A(n,14)=Wa(p)*(0.66+abs(A(n,8)/6)*0.23); %water level
end
A(n,11)=(A(n,9)*(A(n,4))^2+1)*A(n,10);        %factor=y=a*x^2+1

%max current velocity
switch A(n,8)
   case -6
      A(n,12)=A(n,11)*0.5719;
   case -5
      A(n,12)=A(n,11)*0.4967;
   case -4
      A(n,12)=A(n,11)*0.3860;
   case -3
      A(n,12)=A(n,11)*0.2089;
   case -2
      A(n,12)=A(n,11)*0.0997;
   case -1
      A(n,12)=A(n,11)*0.7095;
   case 0
      A(n,12)=A(n,11)*0.8744;
   case 1
      A(n,12)=A(n,11)*0.5959;
```

```
    case 2
       A(n,12)=A(n,11)*0.4190;
    case 3
       A(n,12)=A(n,11)*0.1964;
    case 4
       A(n,12)=A(n,11)*0.2491;
    case 5
       A(n,12)=A(n,11)*0.5301;
    otherwise
       A(n,12)=A(n,11)*0.5699;
end
```

3. Analysis output data

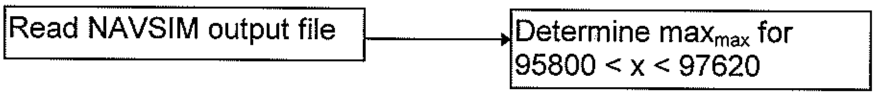


Figure 7 Flow diagram Analysis_output

The file can be found in **D:\Matlab\Analysis_output (CD ROM)**

```
%Analysis_output
clc
clear
load D:\Input_files\NAVSIM_output\alt_0\Cond_1.out
E(:,1)=Cond_1(:,1);
E(:,2)=Cond_1(:,2);
E(:,3)=Cond_1(:,3);
E(:,4)=Cond_1(:,7);
E(:,5)=Cond_1(:,8);

L=300;
B=48.3;
alfa=100.5;
a=1/(tan(alfa*2*pi/360));
b=115854.9;

for m=1:size(E)
   if E(m,2)<95800
      p=m+1;
   end
   if E(m,2)<97620
      q=m;
   end
end

n=1;
while [n,1]<=size(E)
   c(n)=E(n,3)+1/a*E(n,2);

   x(n)=(c(n)-b)/(a+1/a);
   y(n)=a*x(n)+b;
   d(n)=sqrt((E(n,2)-x(n))^2+(E(n,3)-y(n))^2);
   e(n)=L/2*abs(sin((E(n,4)-alfa)*2*pi/360))+B/2*abs(cos((E(n,4)-
alfa)*2*pi/360));
```

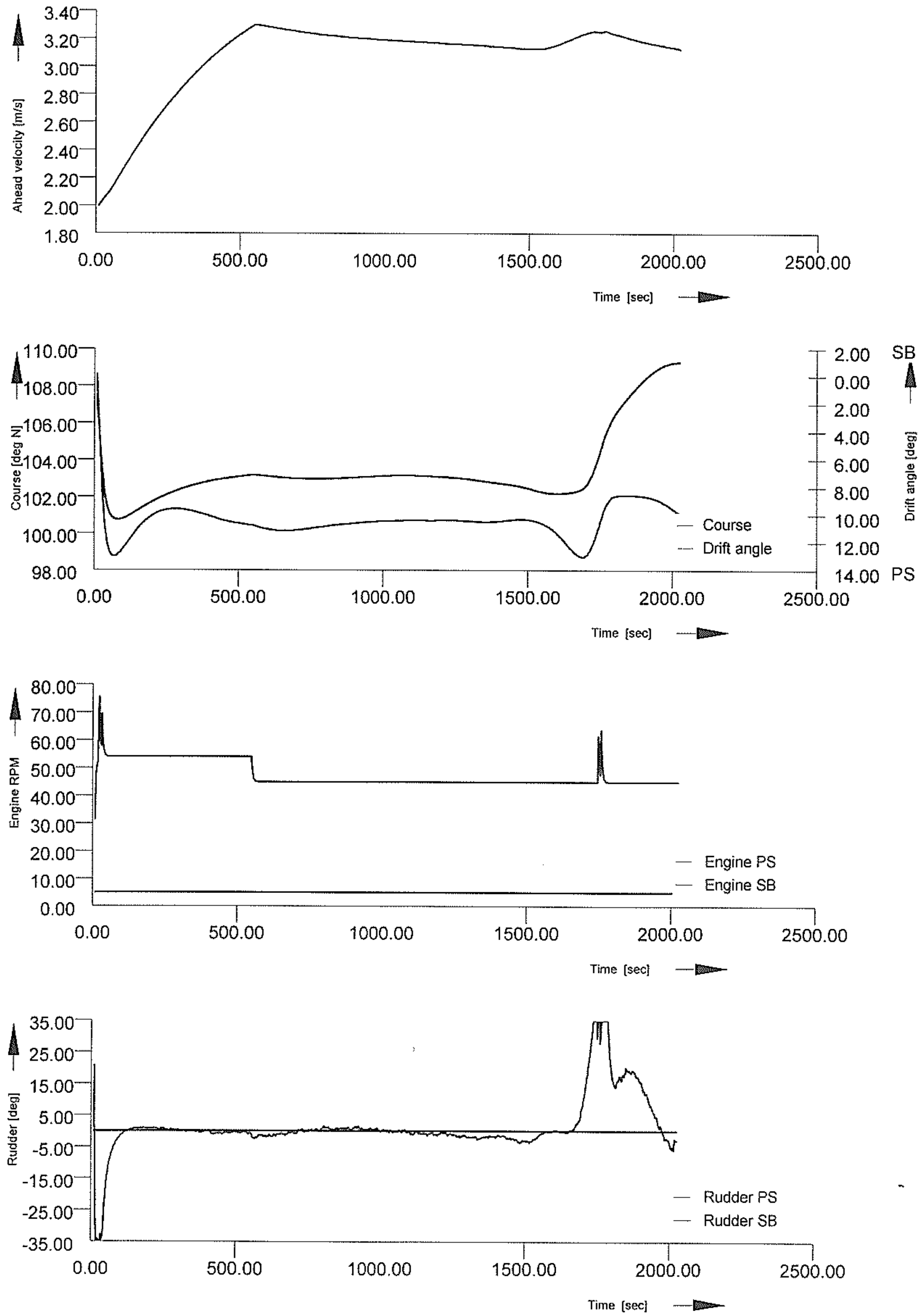
```
   if E(n,2)<x(n)
      port(n)=-d(n)+e(n);
      star(n)=-d(n)-e(n);
   else
      port(n)=d(n)+e(n);
      star(n)=d(n)-e(n);
   end
   n=n+1;
end

dev=max(port(p:q))
dev1=min(port(p:q))
dev2=min(star(p:q))
dev3=max(star(p:q))
```

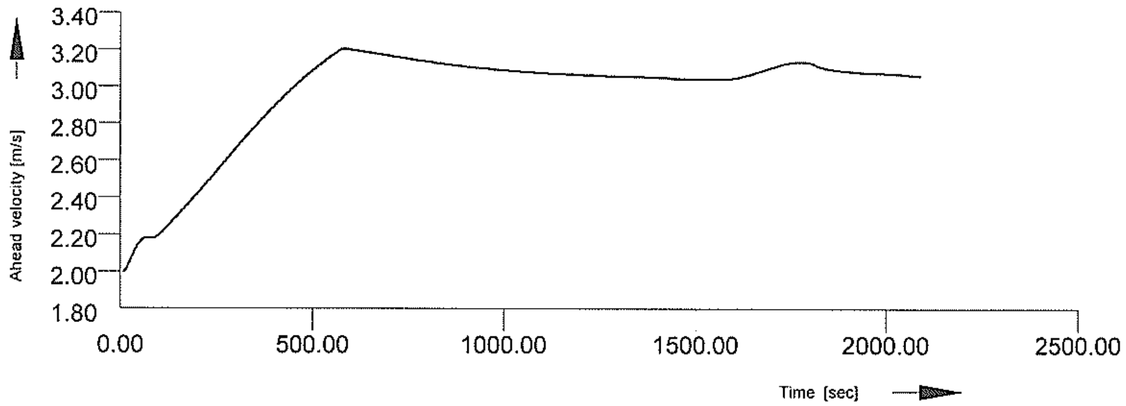
Appendix XVI: Output plots

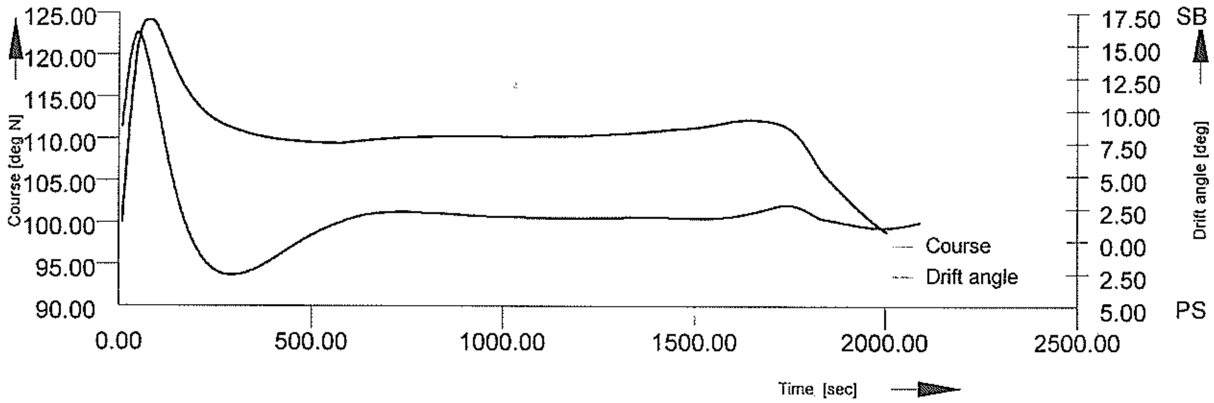
Table of contents:

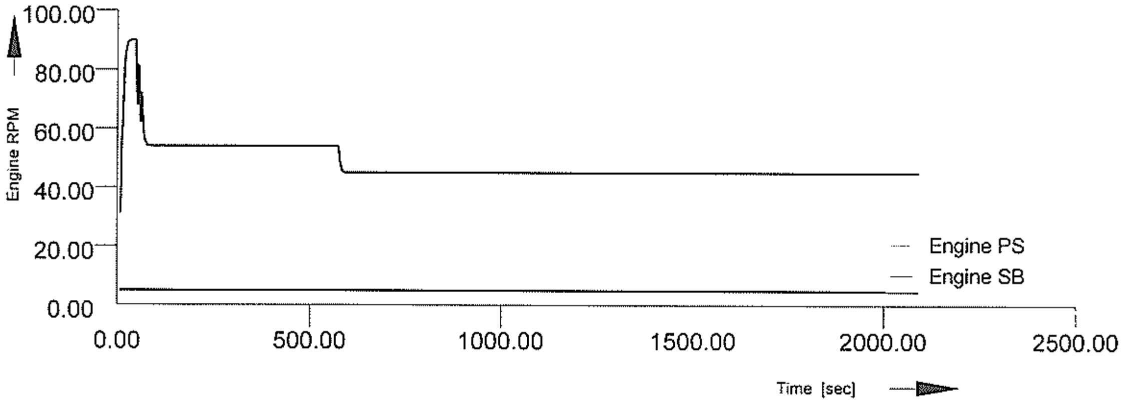
Appendix XVI.1: Fast time runs set I.2a

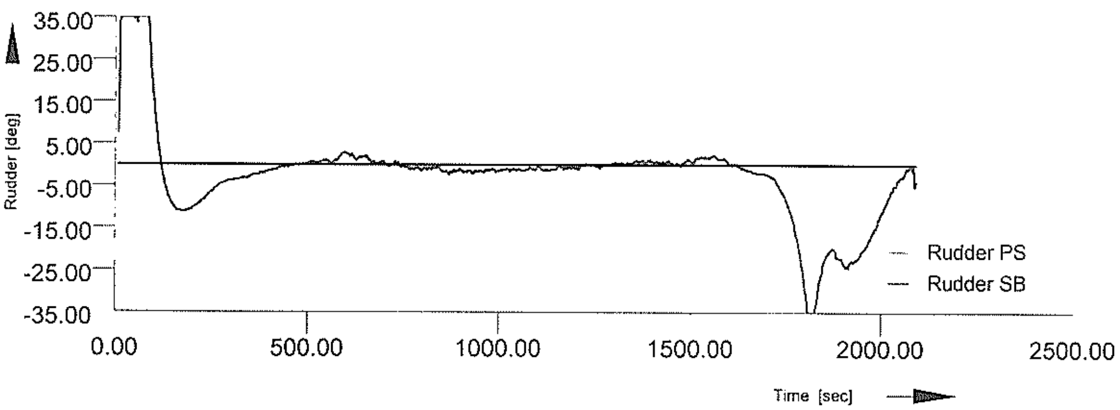


Fast time Set I.2a Condition 2	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	







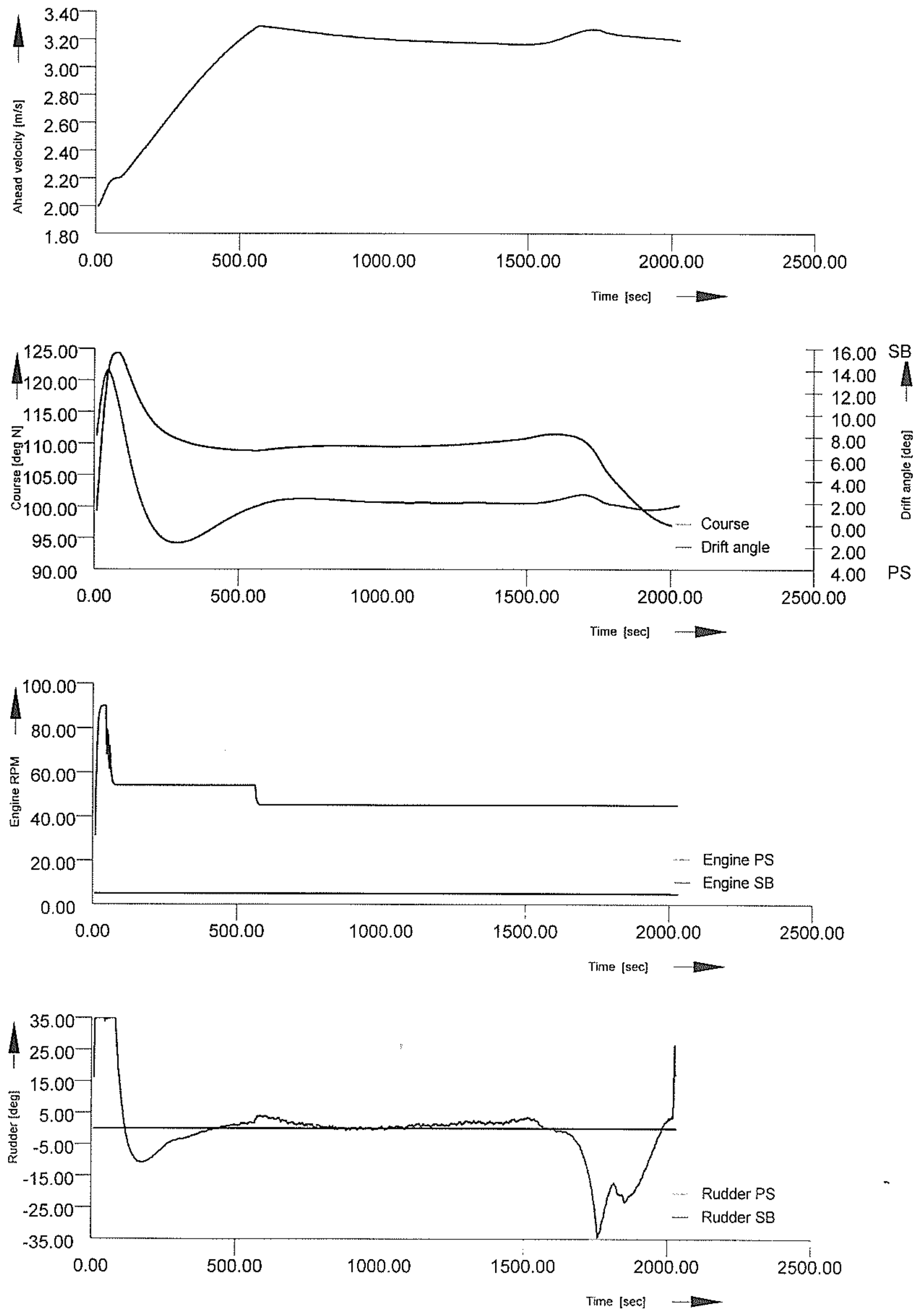


Fast time
Set I.2a
Condition 3

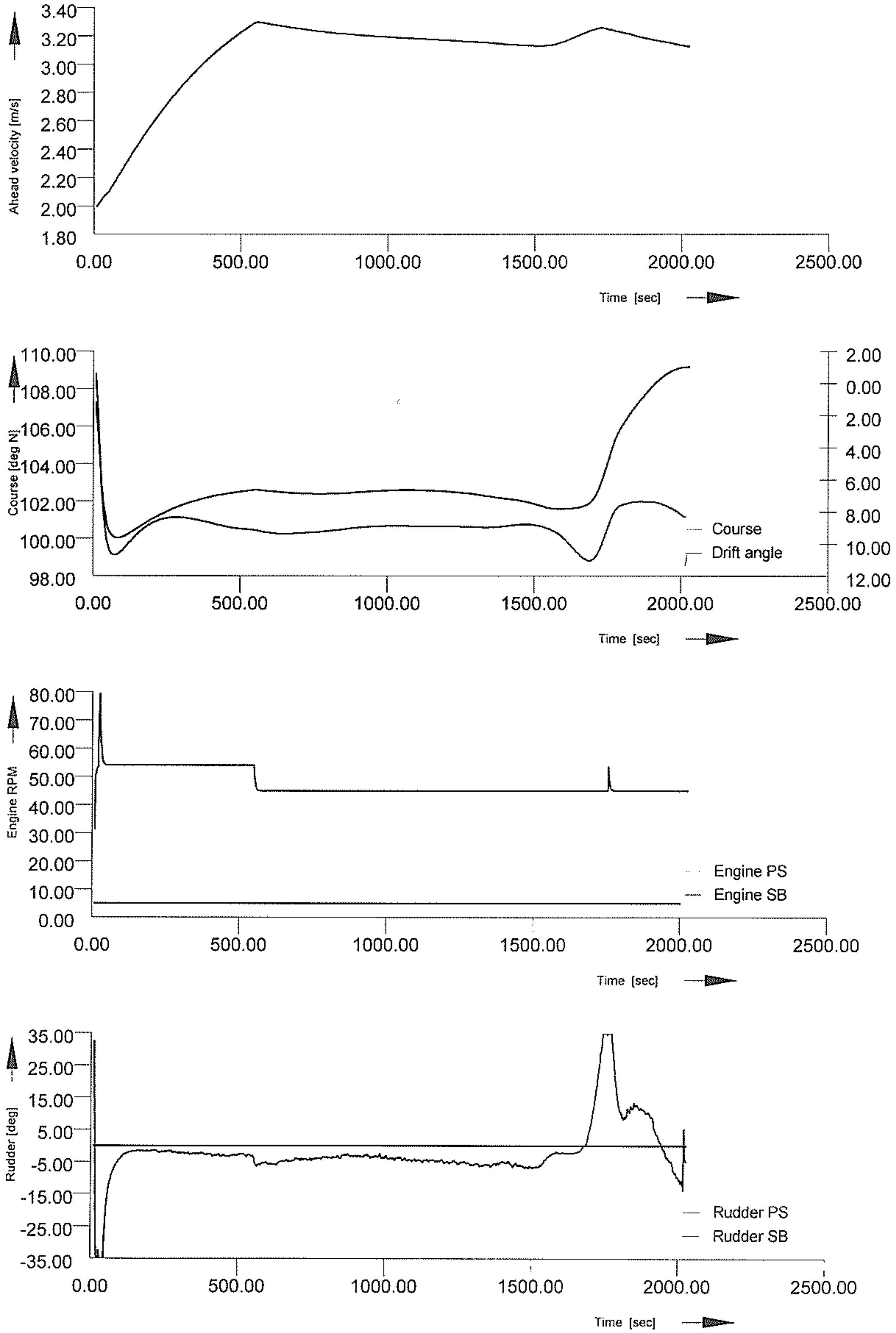
R01
W. Welvaarts
June 2001

AVV Transport Research Centre B010

Alkyon 6/22/01 1:22:37 AM

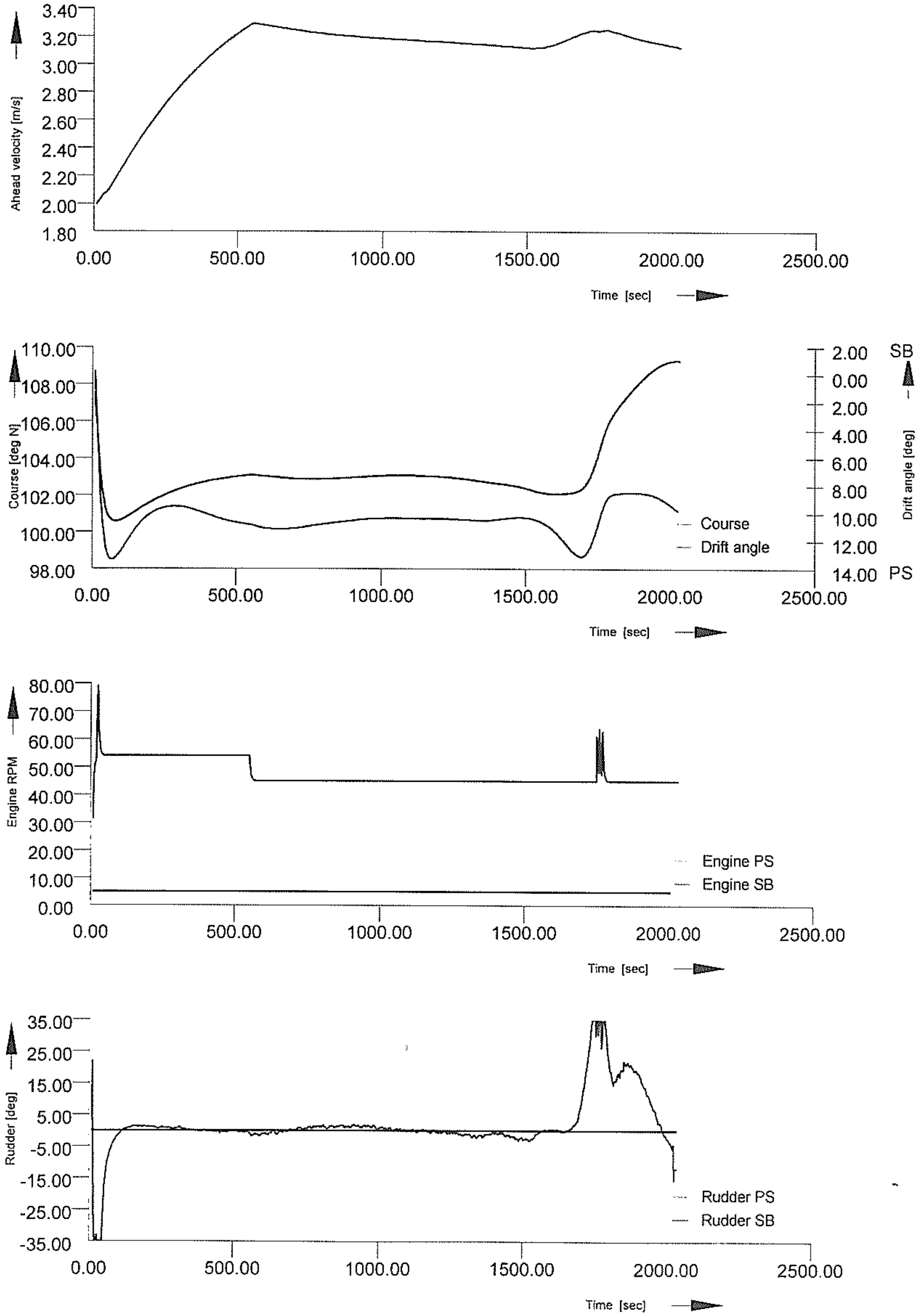


Fast time Set I.2a Condition 4	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

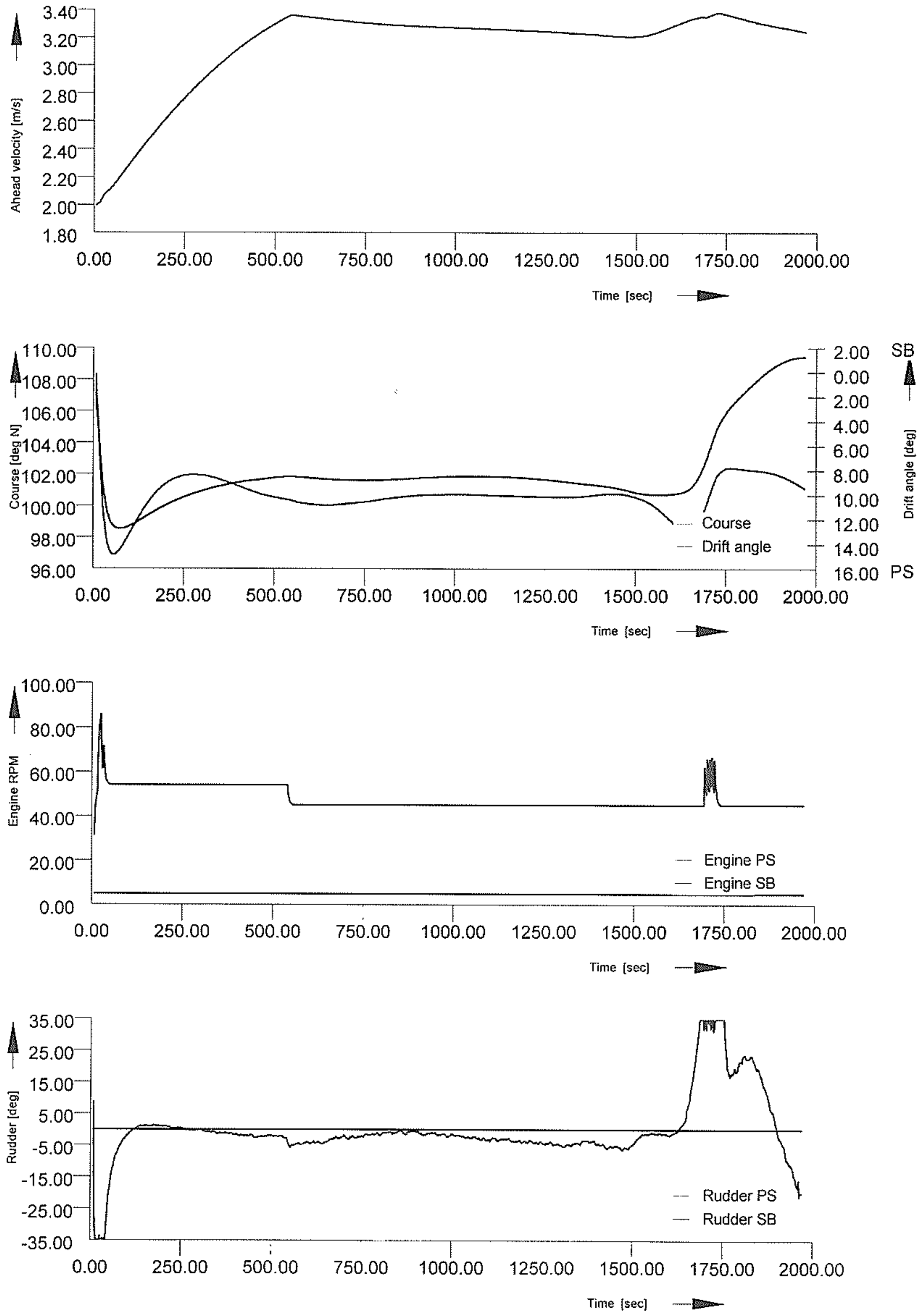


Fast time Set I.2a Condition 5	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 1:32:28 AM



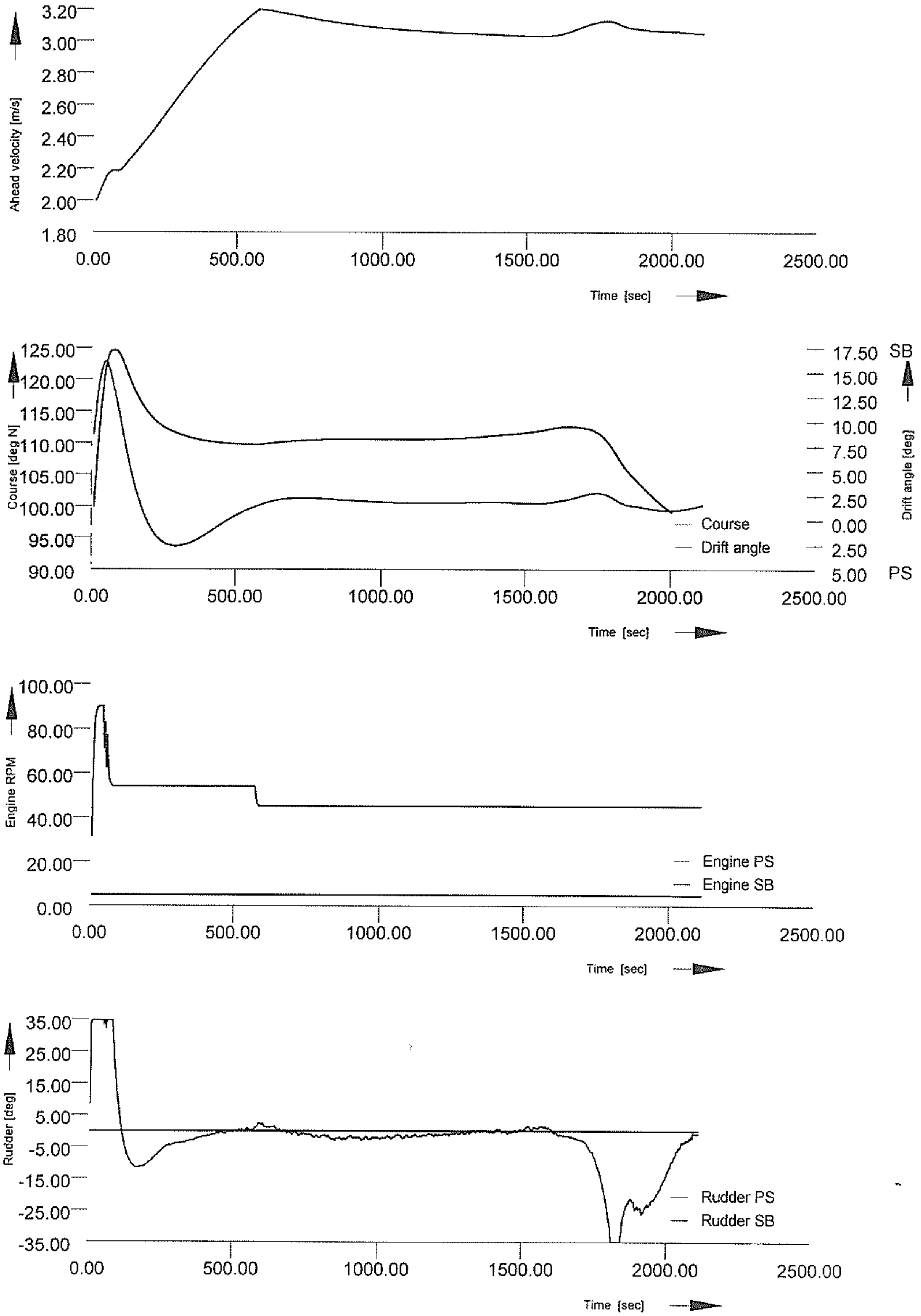
Fast time Set I.2a Condition 8	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	



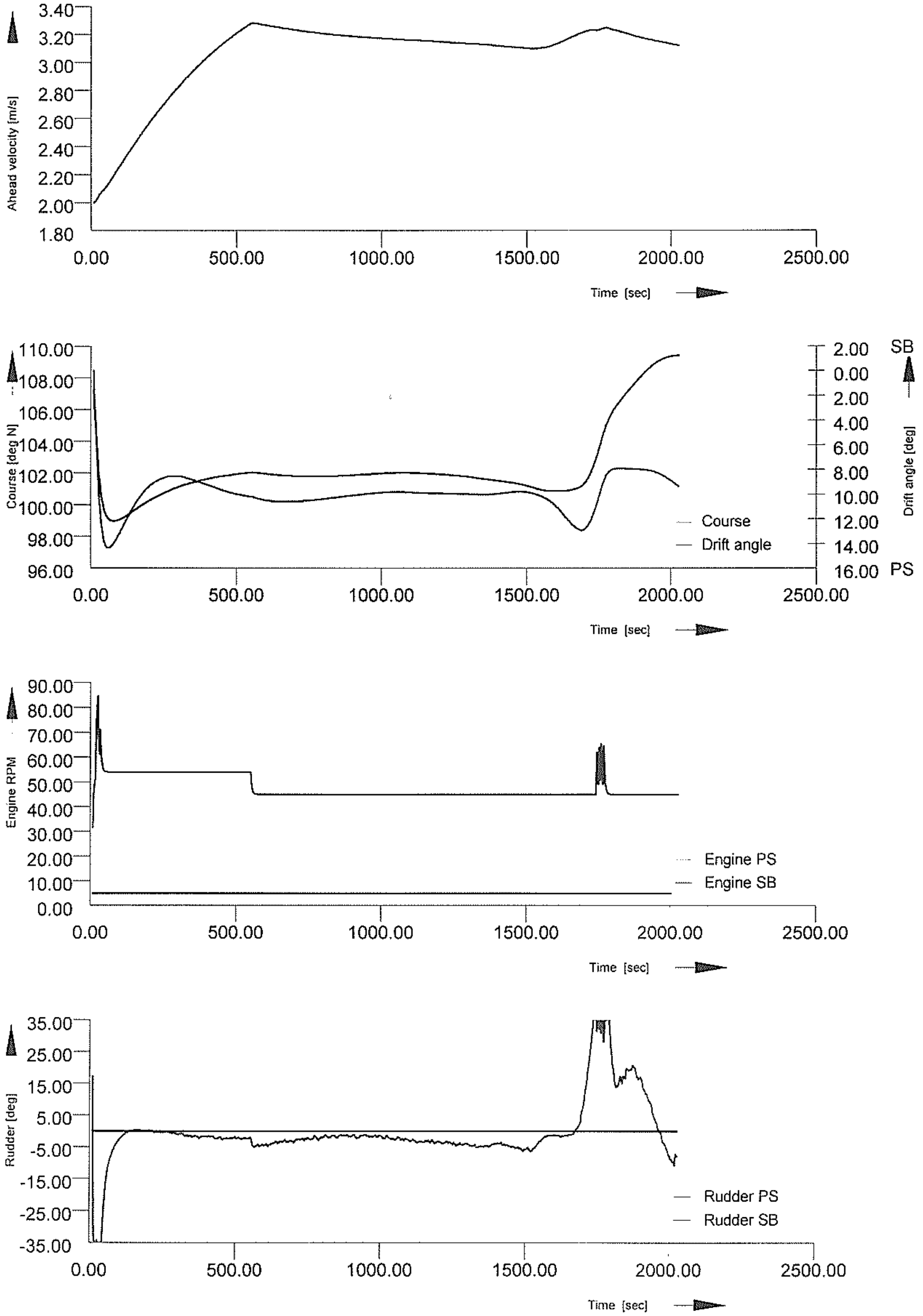
Fast time
Set I.2a
Condition 10

R06
W. Welvaarts
June 2001

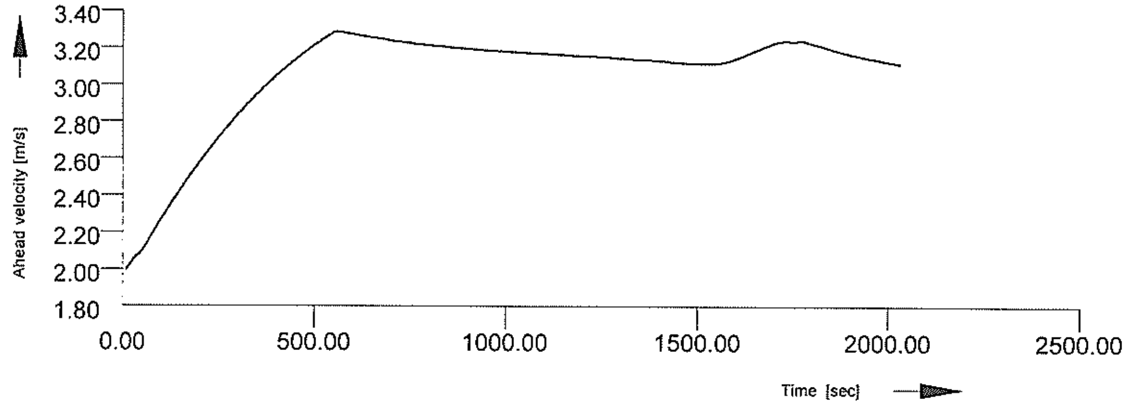
AVV Transport Research Centre
B010

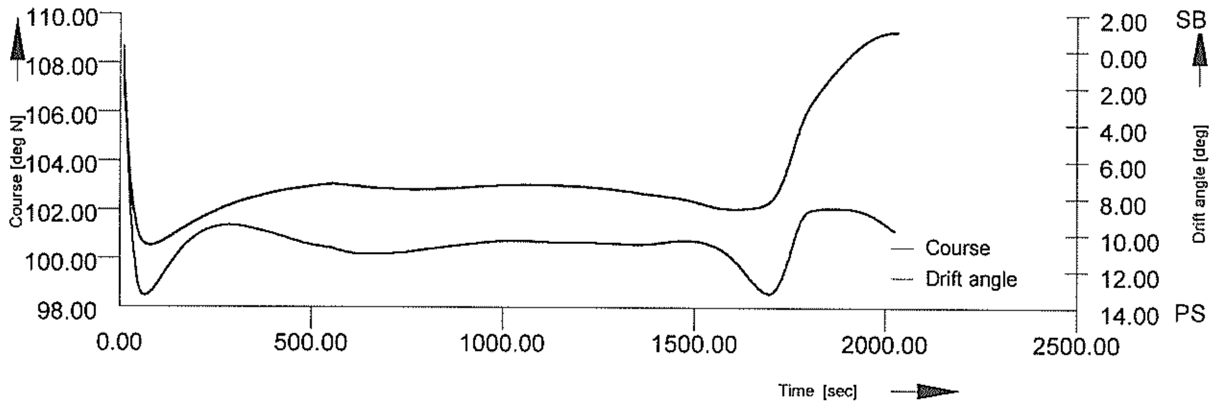


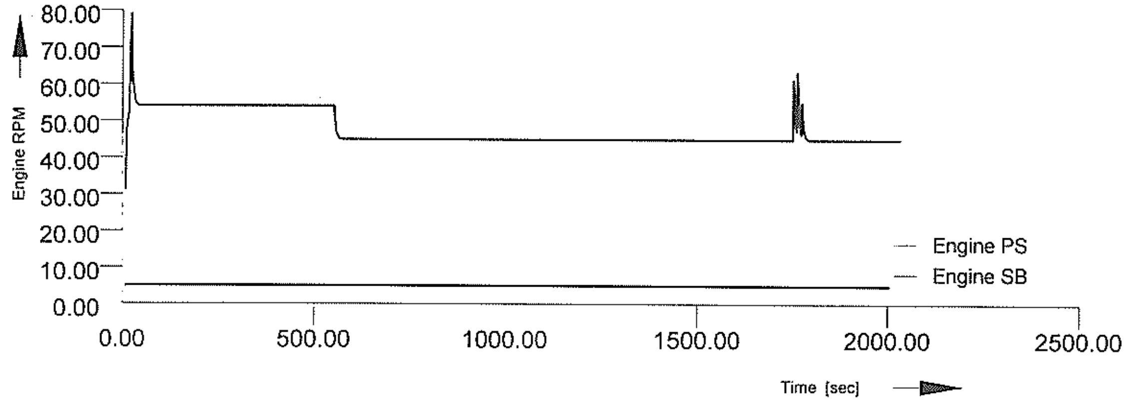
Fast time Set I.2a Condition 15	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

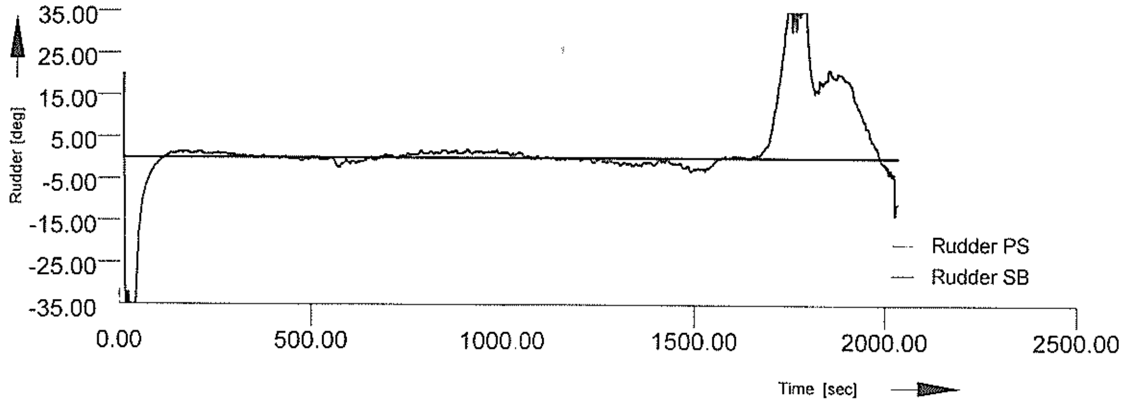


Fast time Set I.2a Condition 16	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	



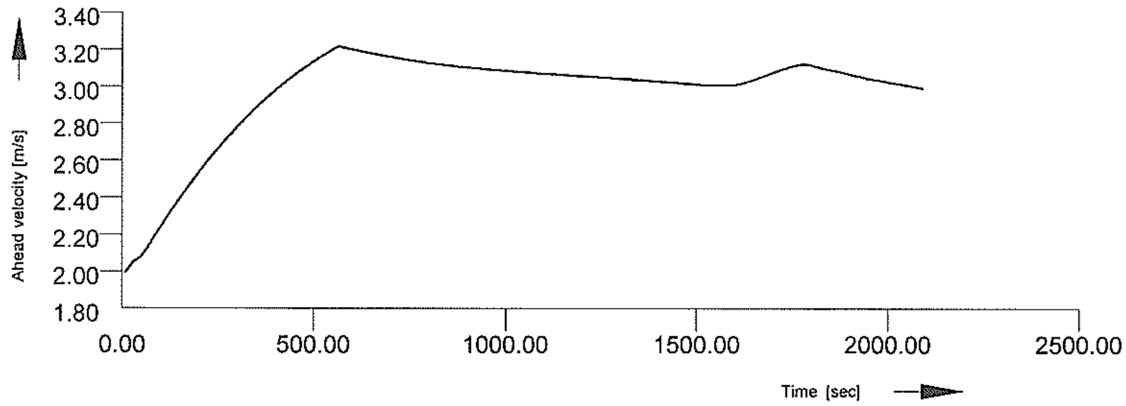


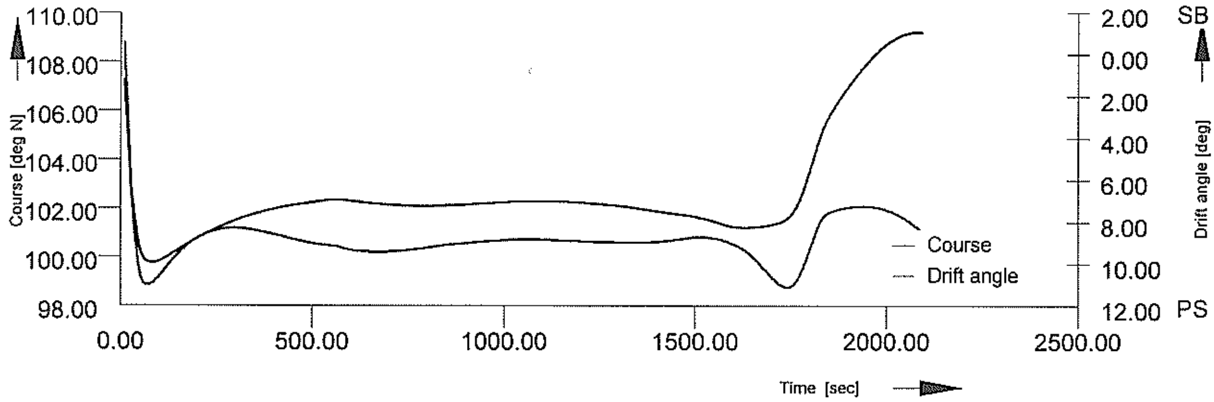


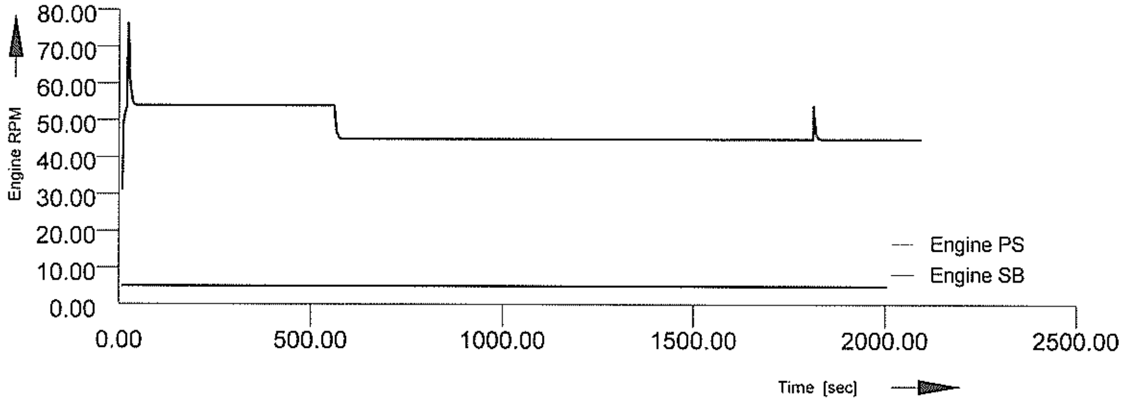


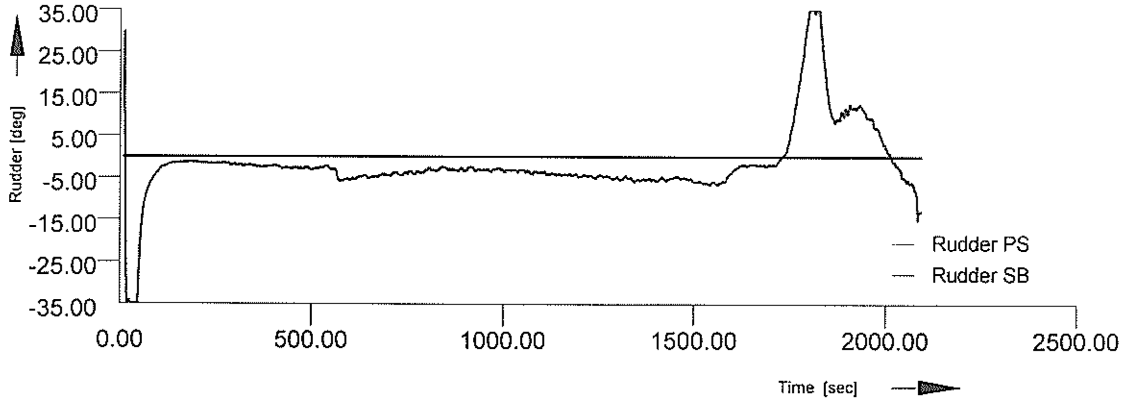
Fast time Set I.2a Condition 17	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 1:10:30 AM

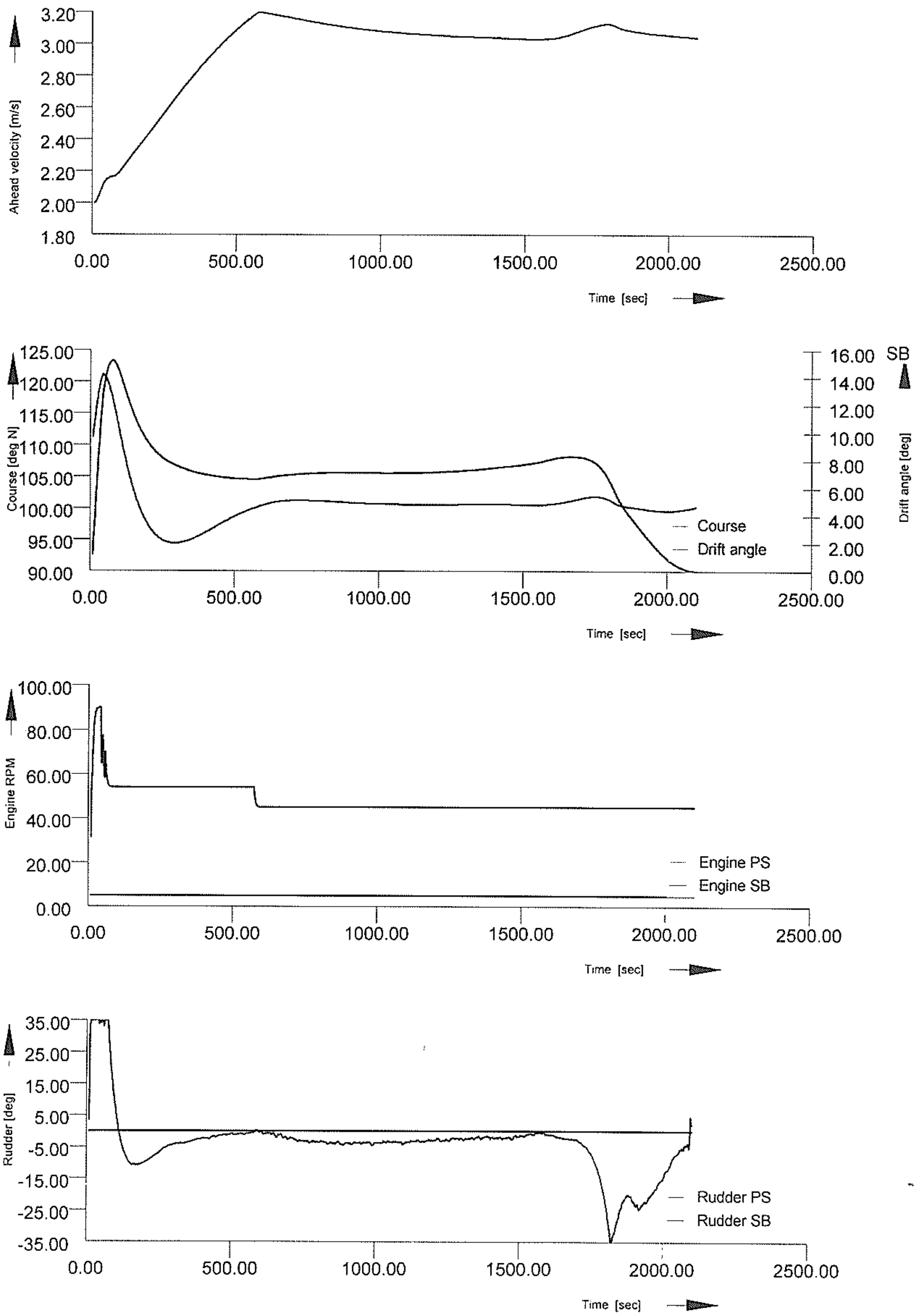






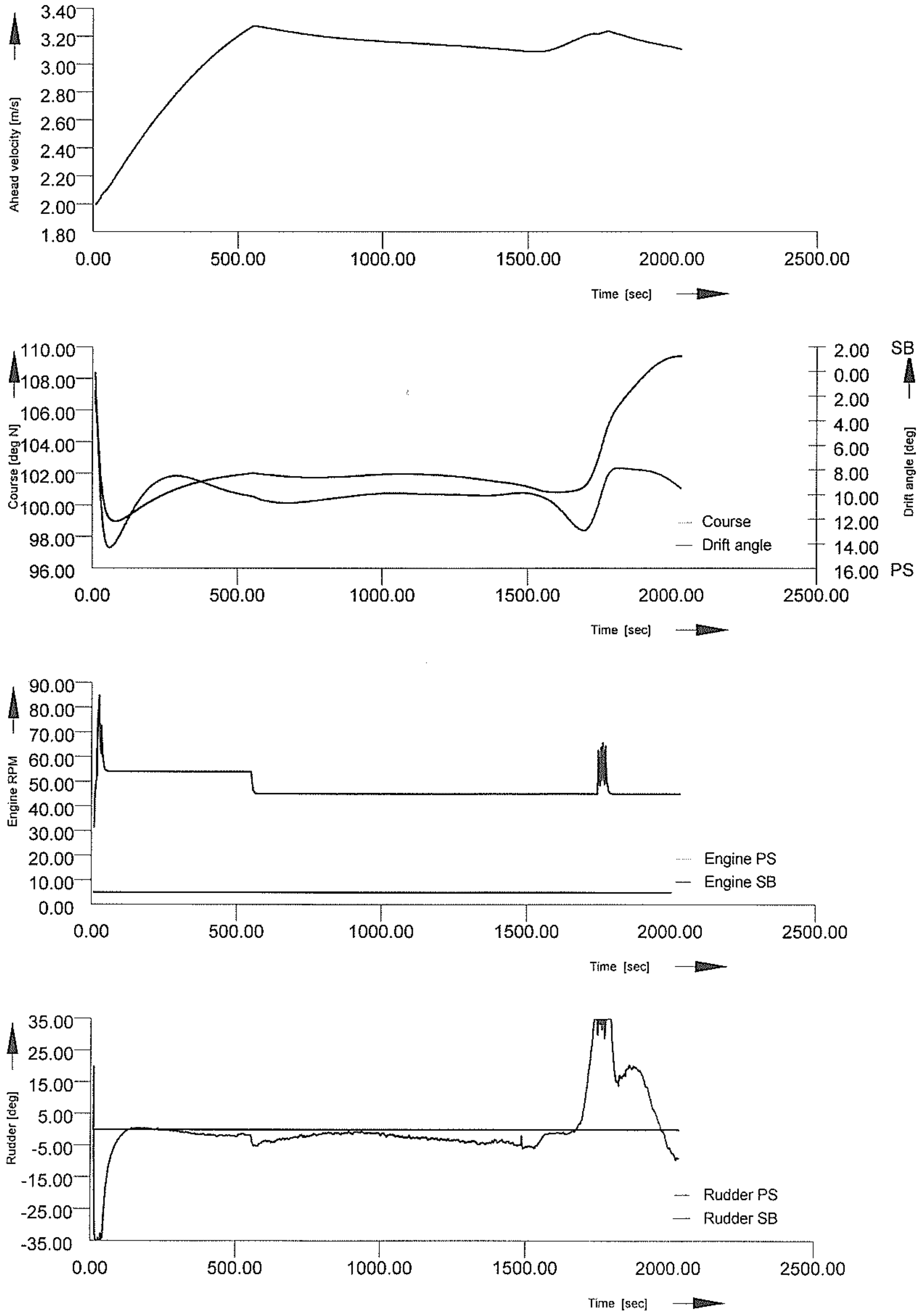


Fast time Set I.2a Condition 21	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

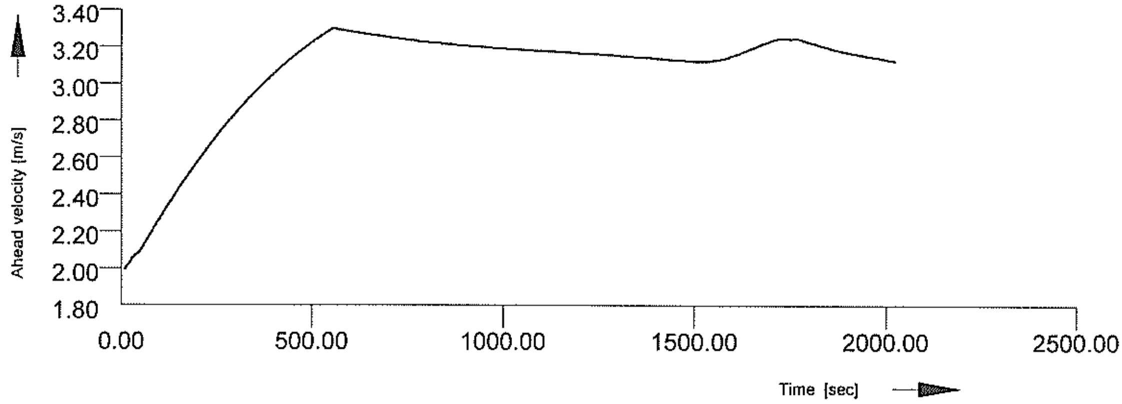


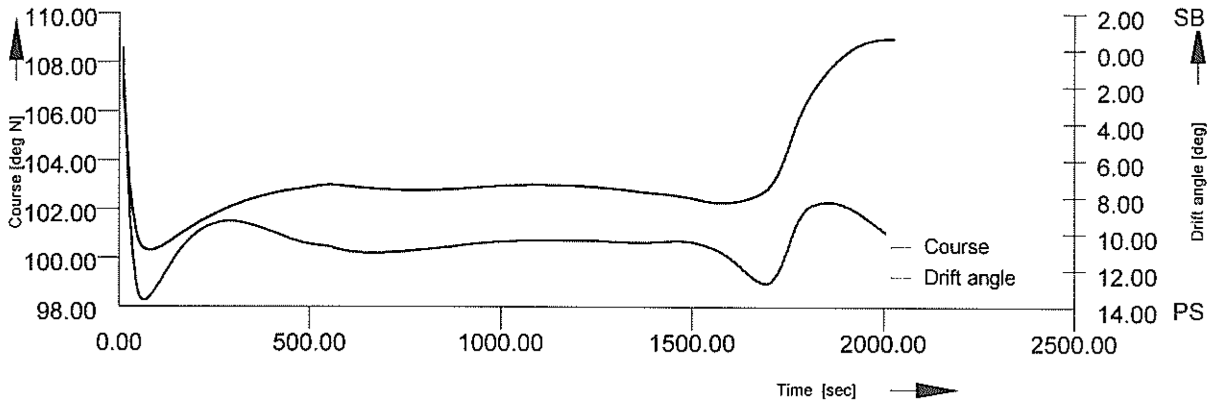
Fast time Set I.2a Condition 23	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

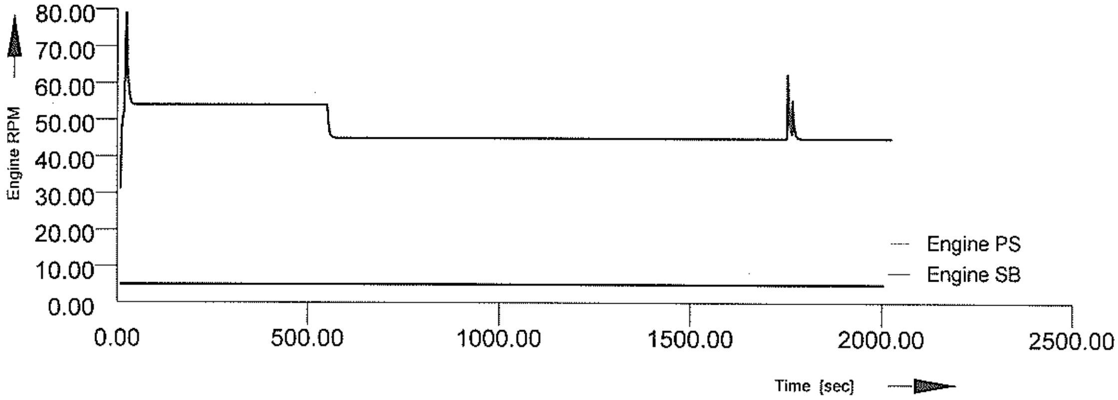
Alkyon 6/22/01 1:11:37 AM

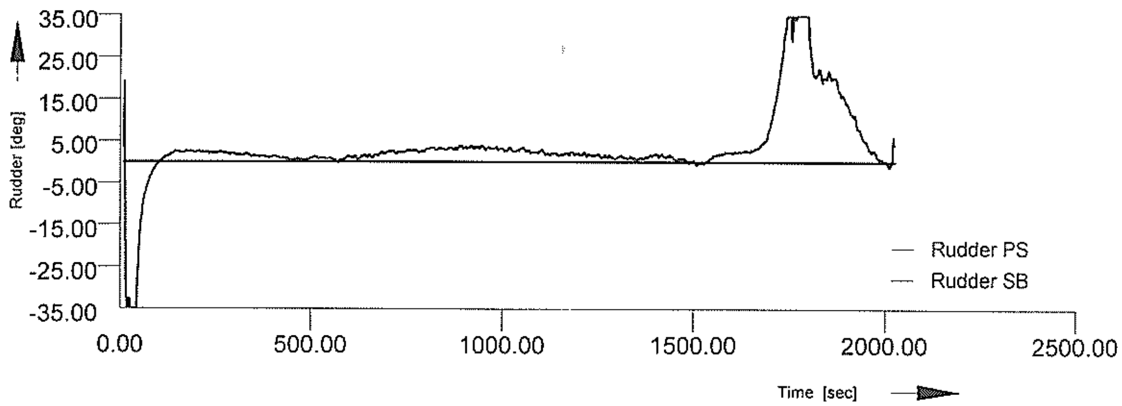


Fast time Set I.2a Condition 25		R01
		W. Welvaarts
		June 2001
AVV Transport Research Centre	B010	

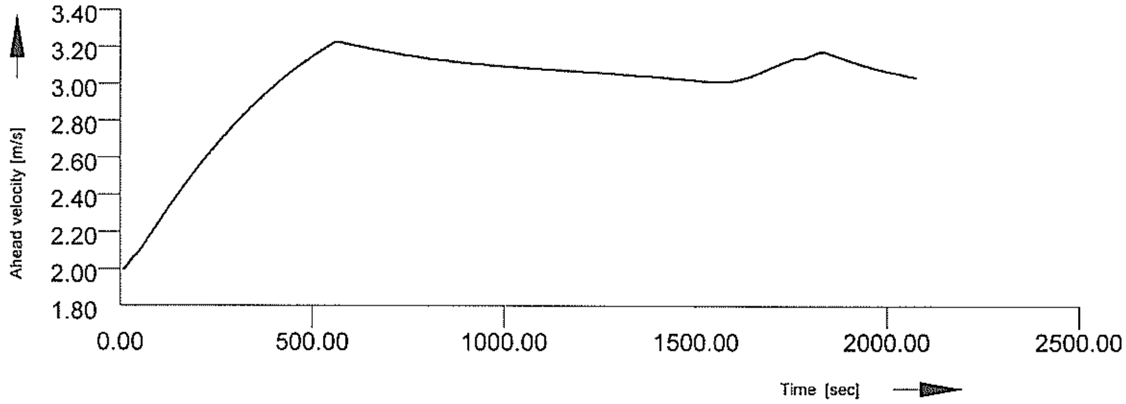


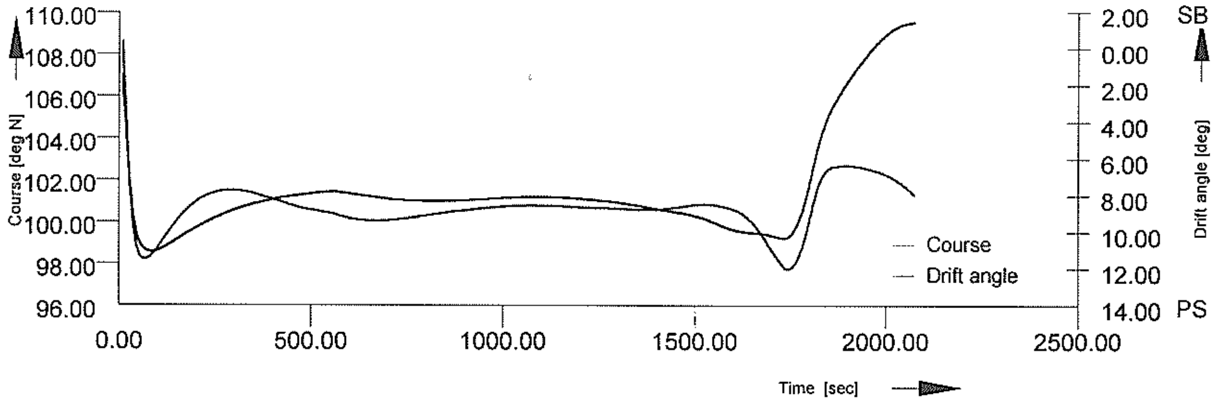


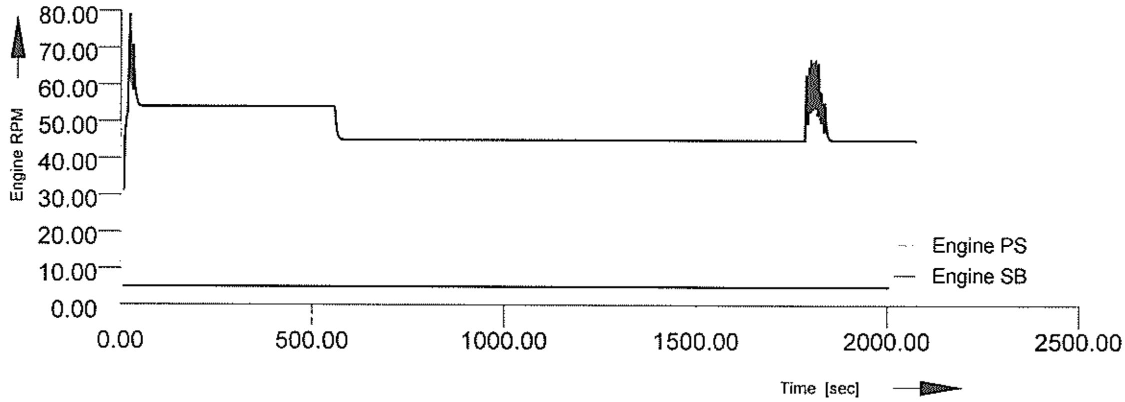


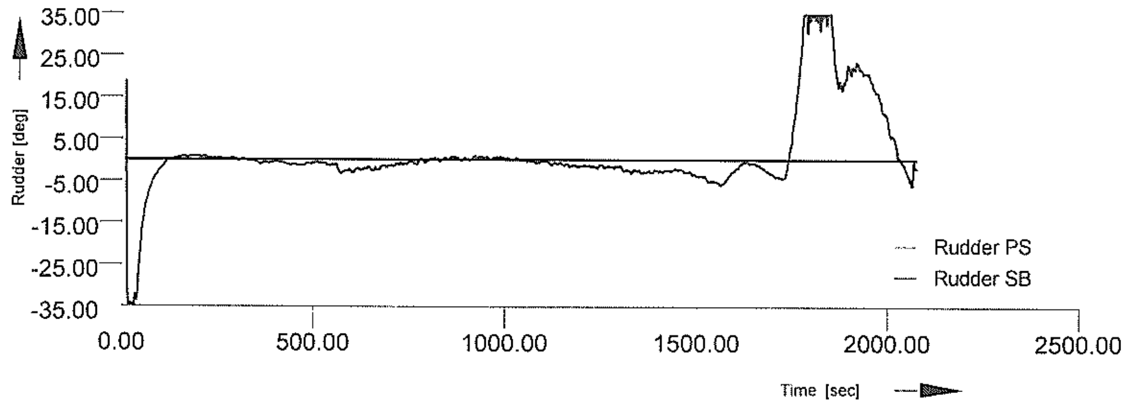


Fast time Set I.2a Condition 26	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

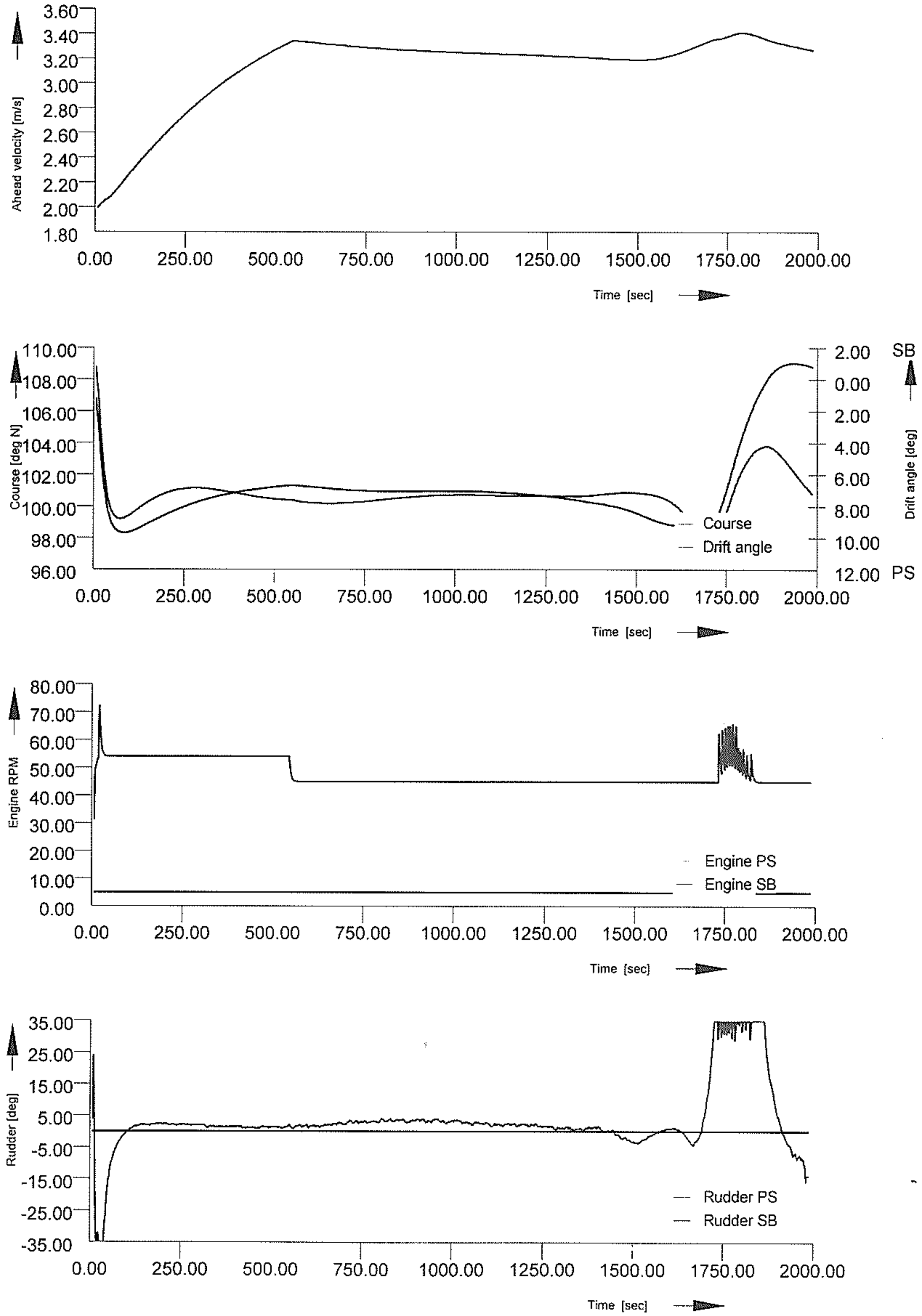




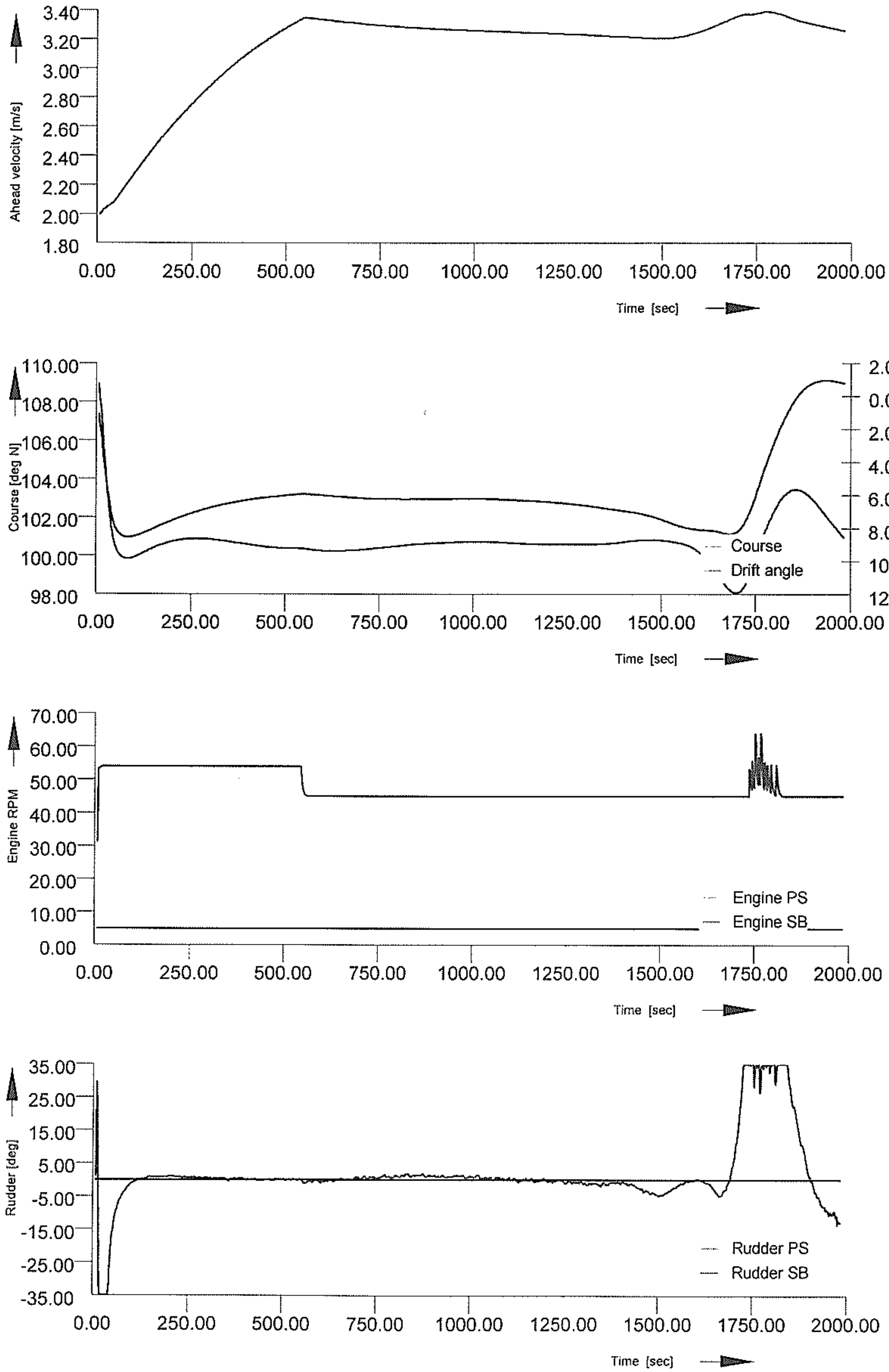




Fast time Set I.2a Condition 28	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

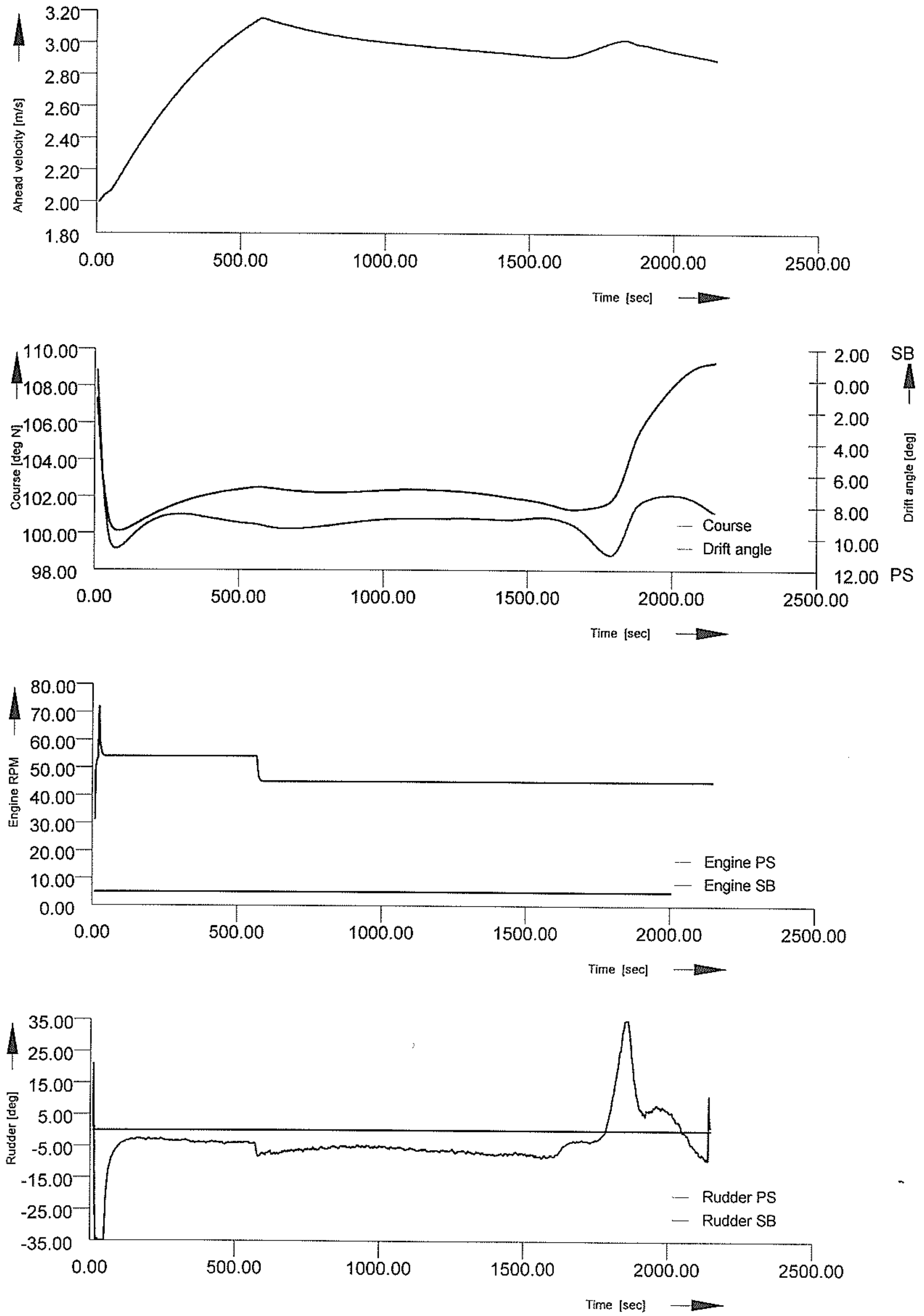


Fast time Set I.2a Condition 32	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		



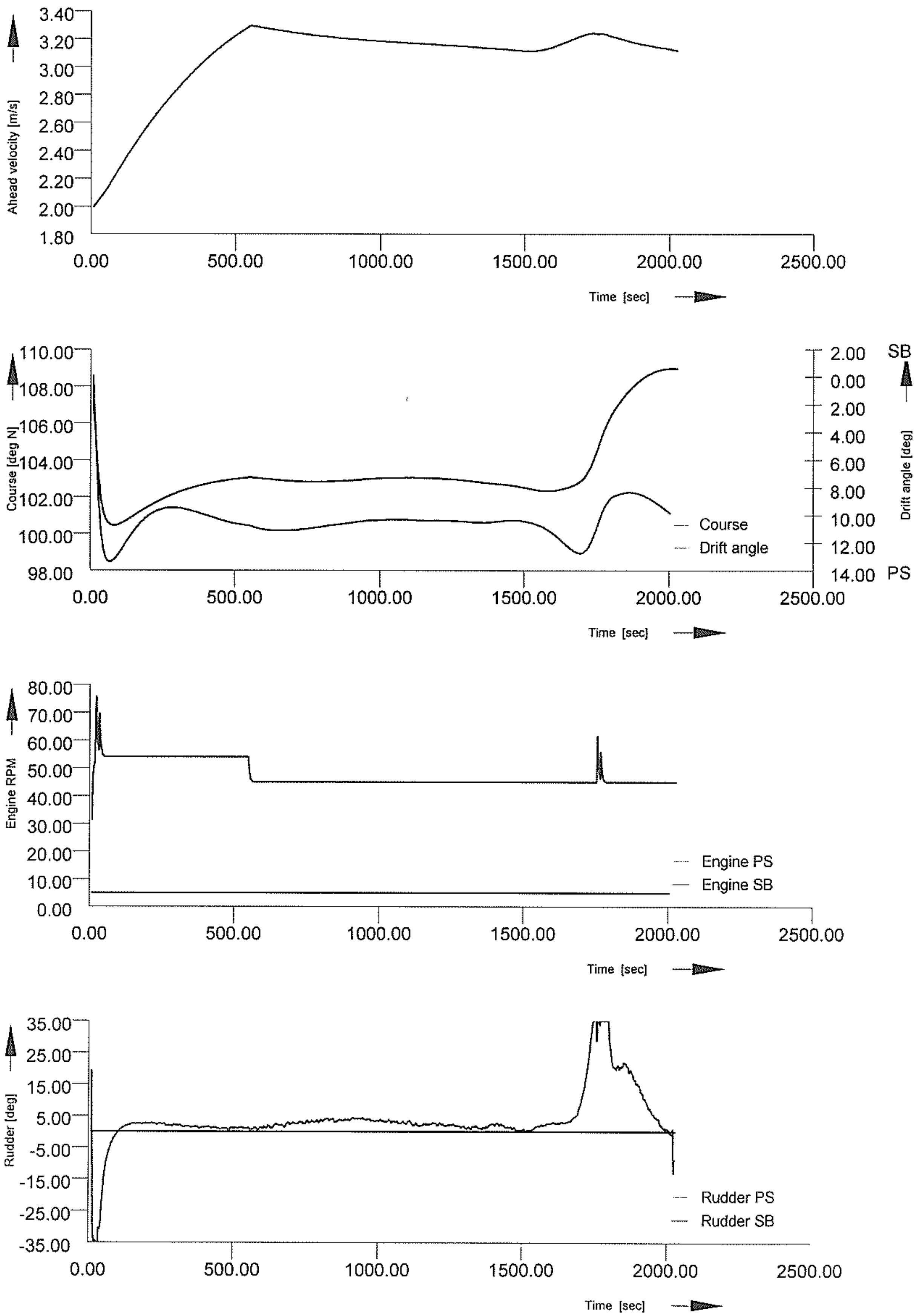
Fast time Set I.2a Condition 33	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

Alkyon 6/22/01 1:20:09 AM

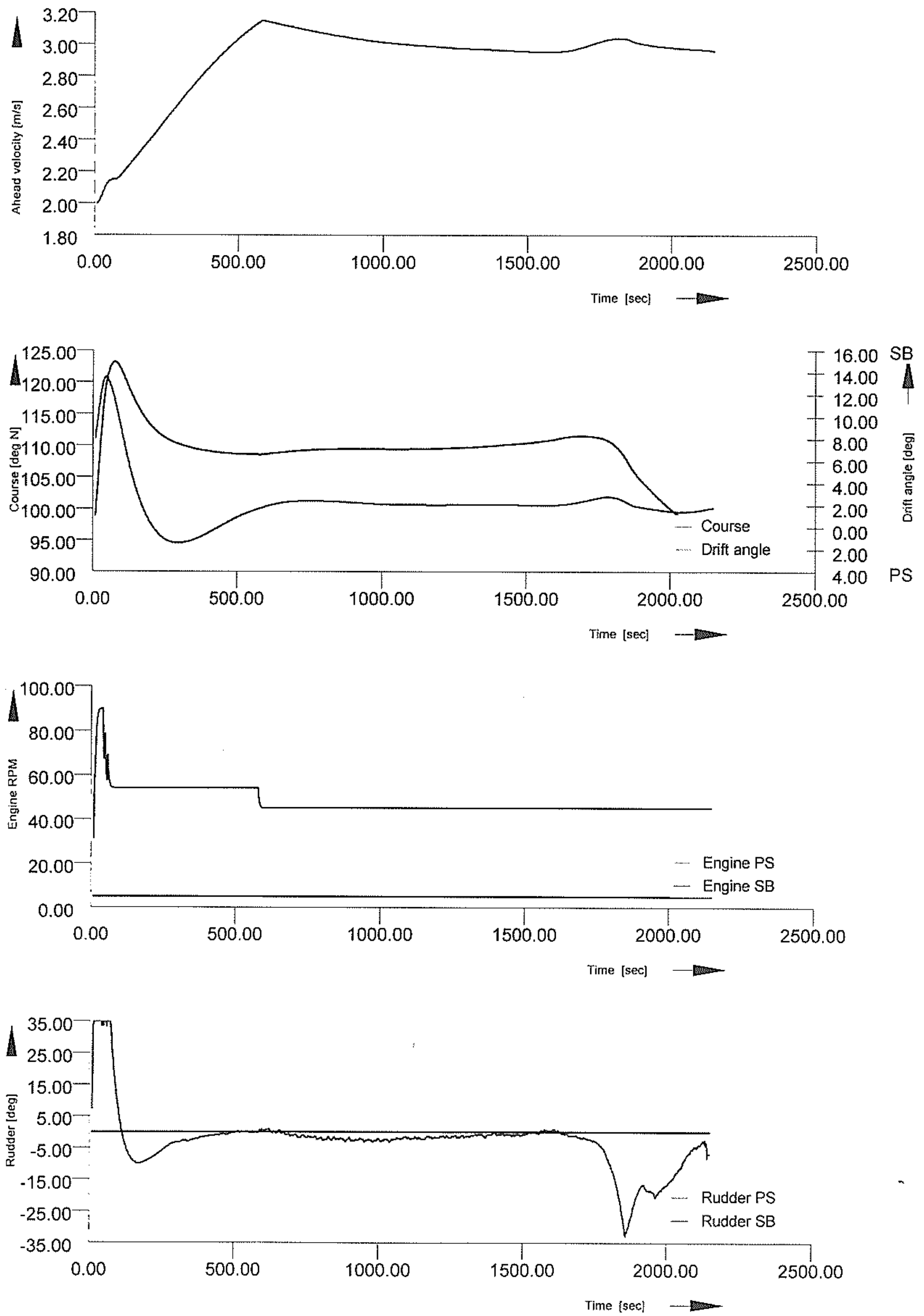


Fast time Set I.2a Condition 34	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 1:20:40 AM

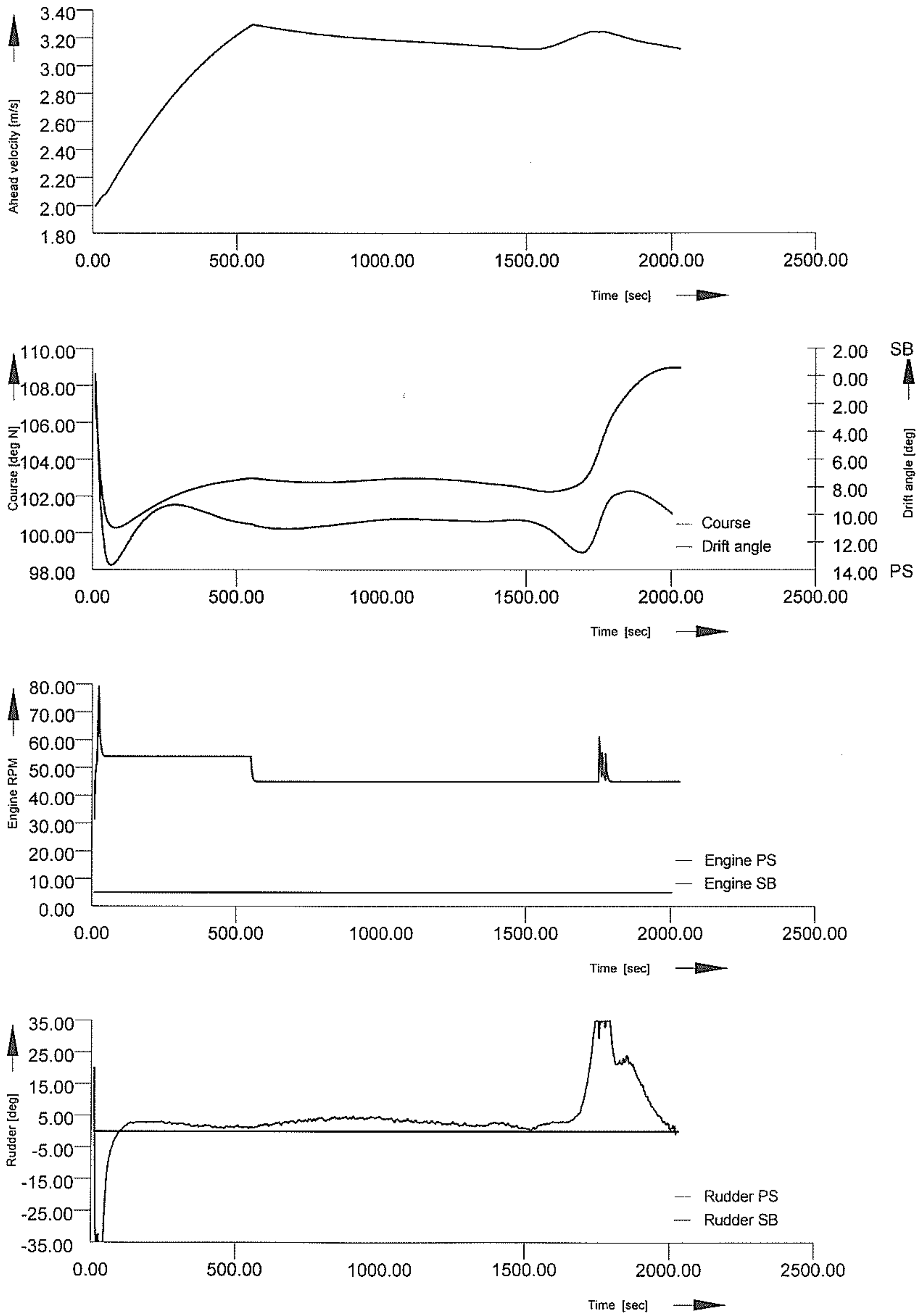


Fast time Set I.2a Condition 36	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

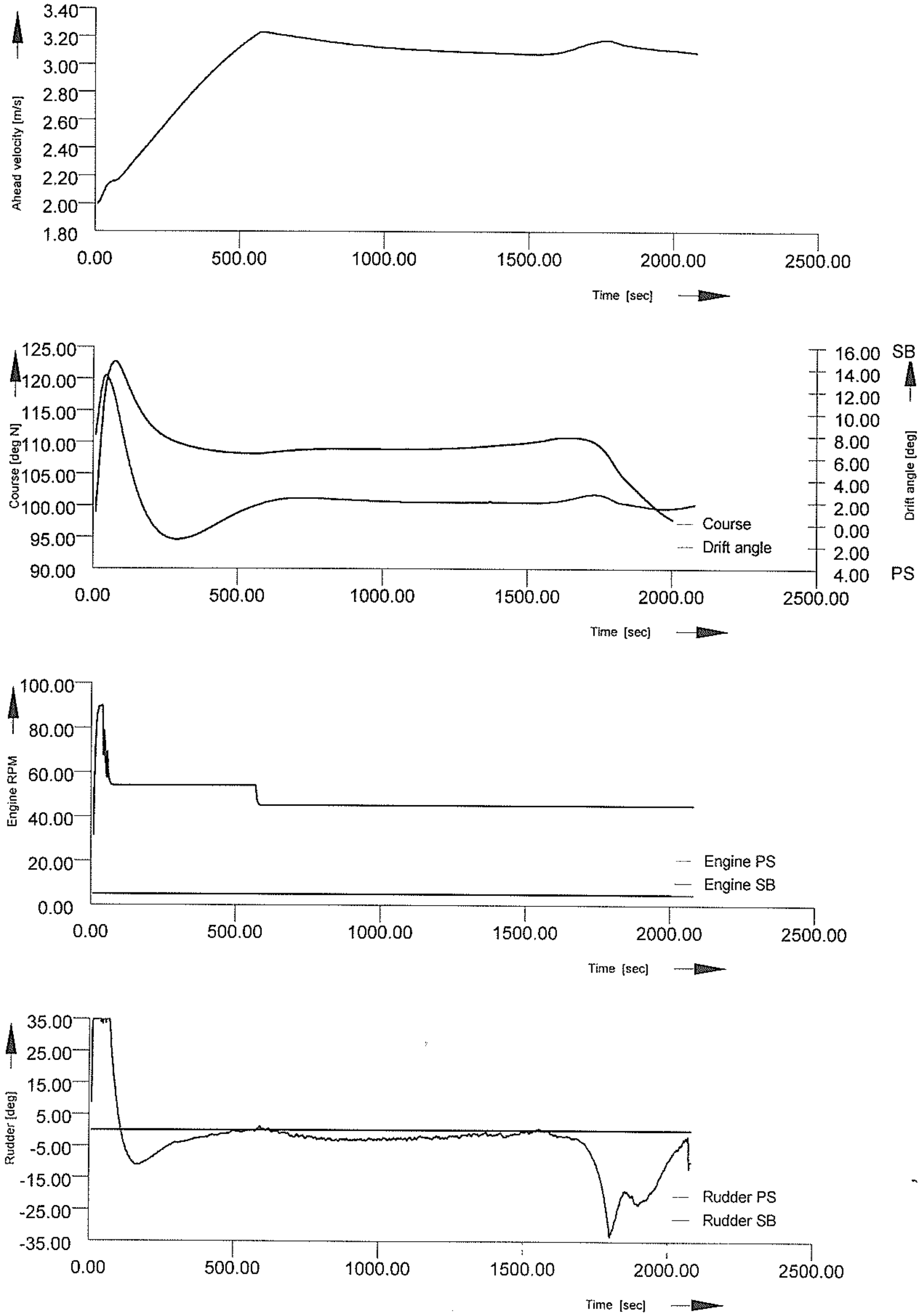


Fast time Set I.2a Condition 39	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

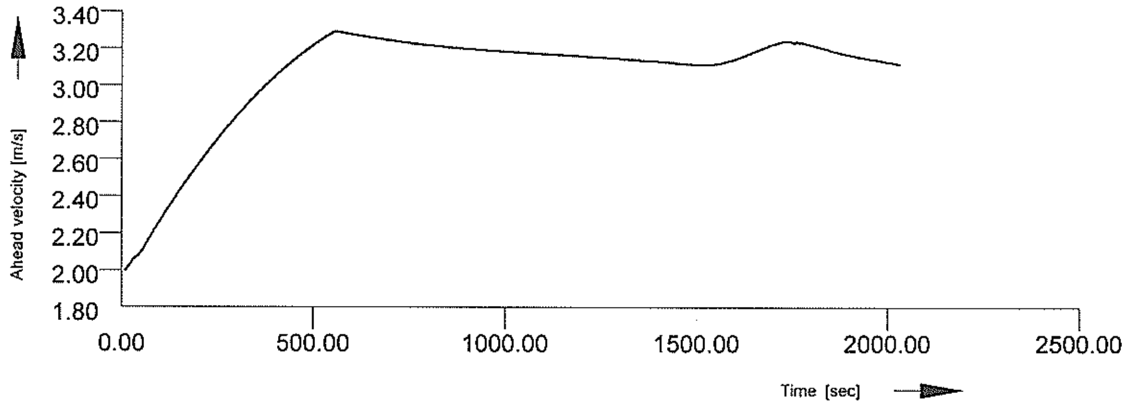
Alkyon 6/22/01 1:24:33 AM

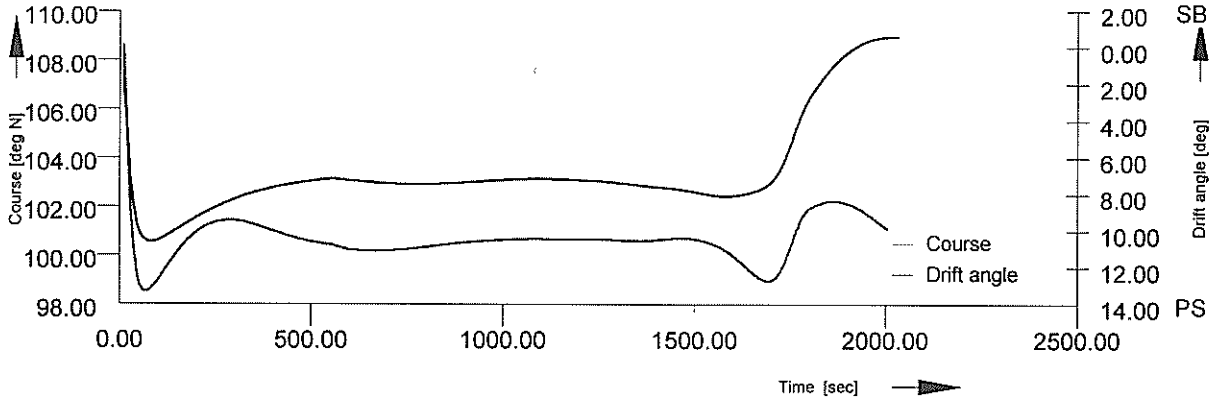


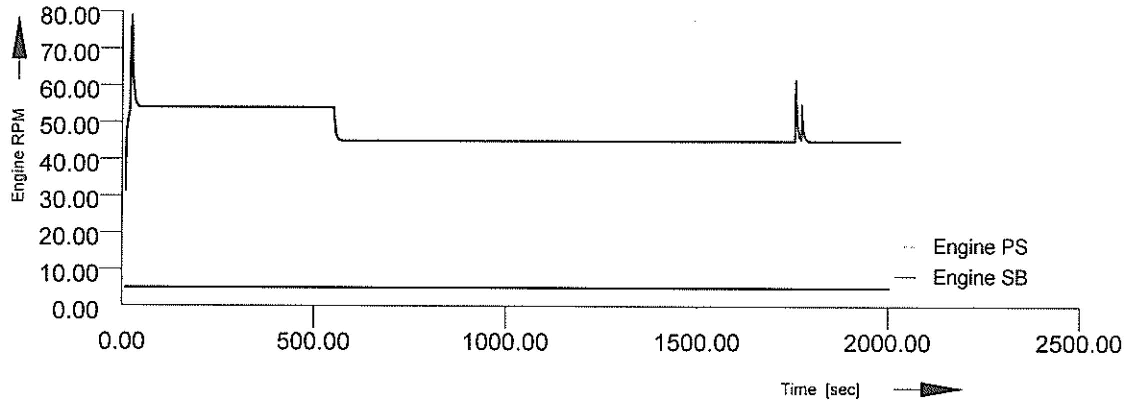
Fast time Set I.2a Condition 40	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

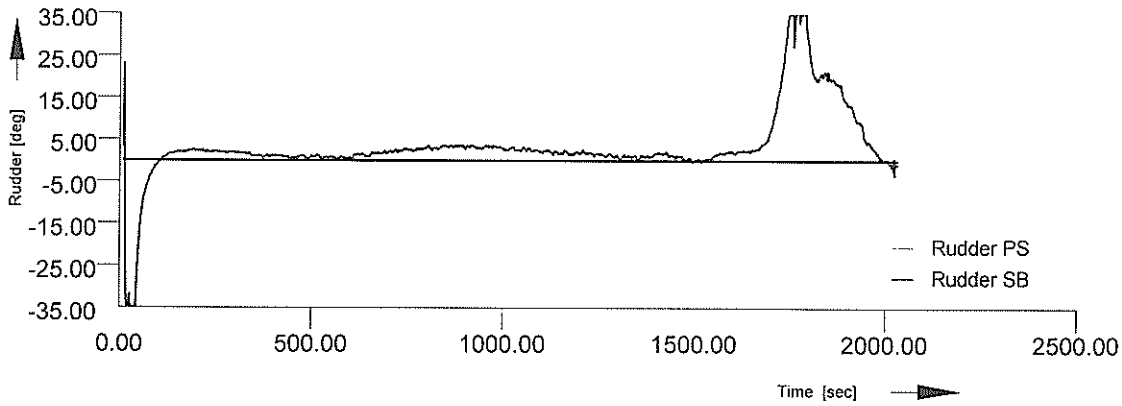


Fast time Set I.2a Condition 41	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	



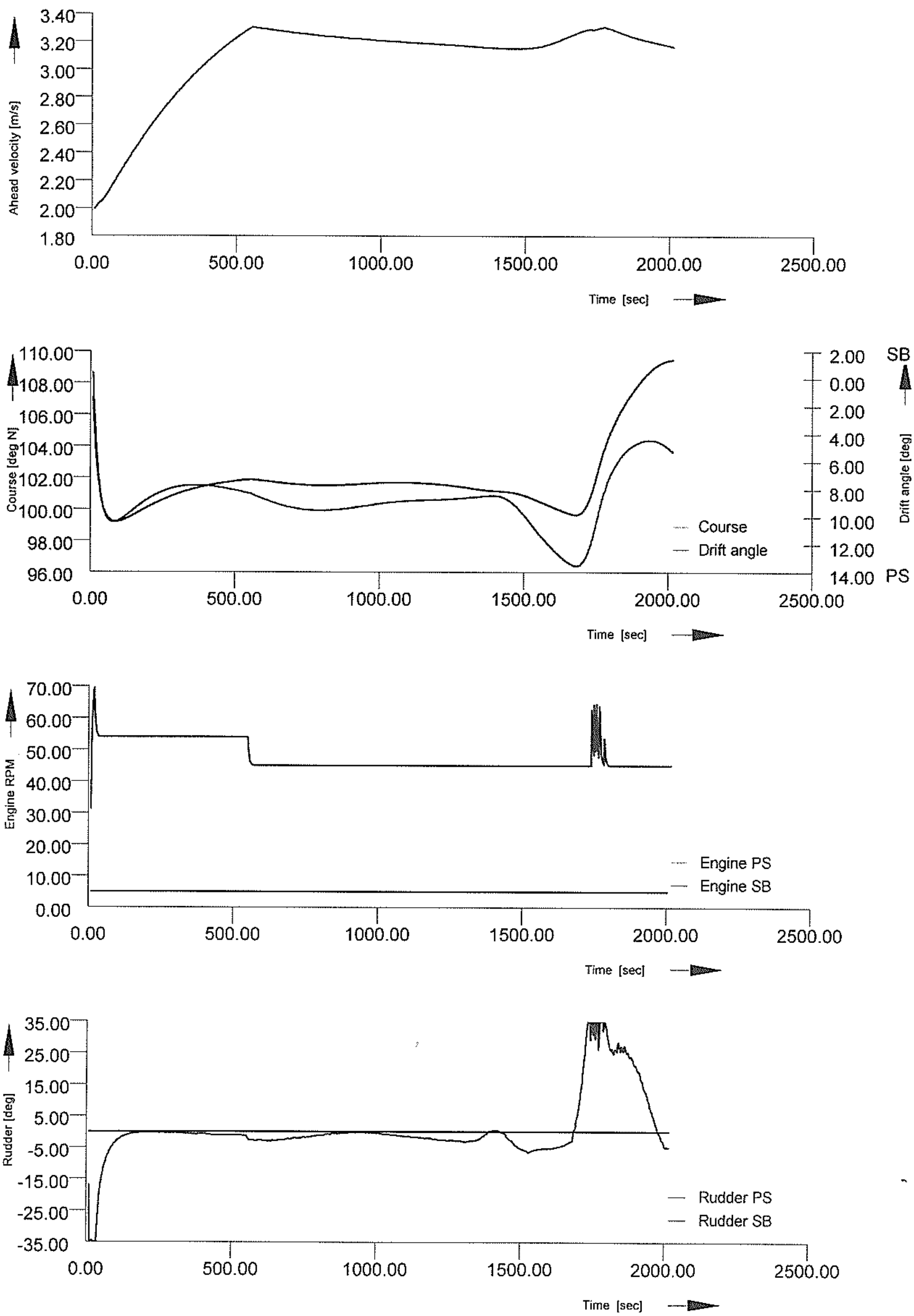




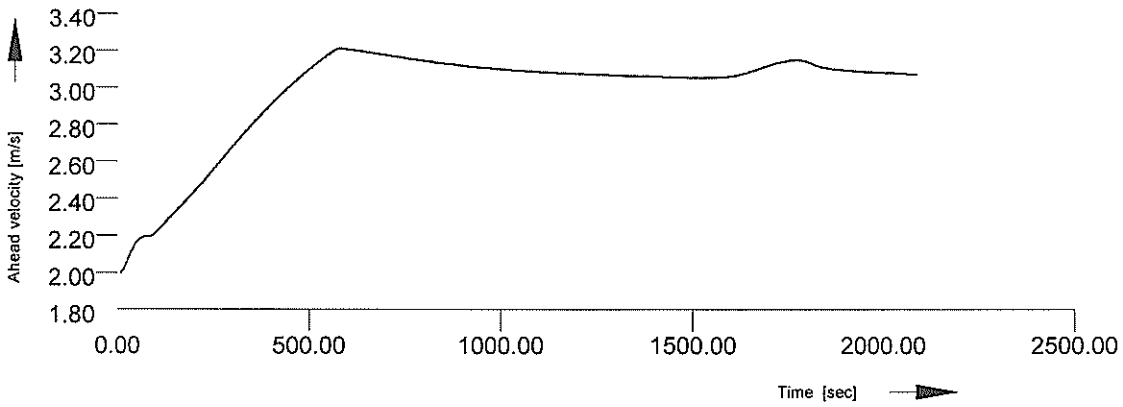


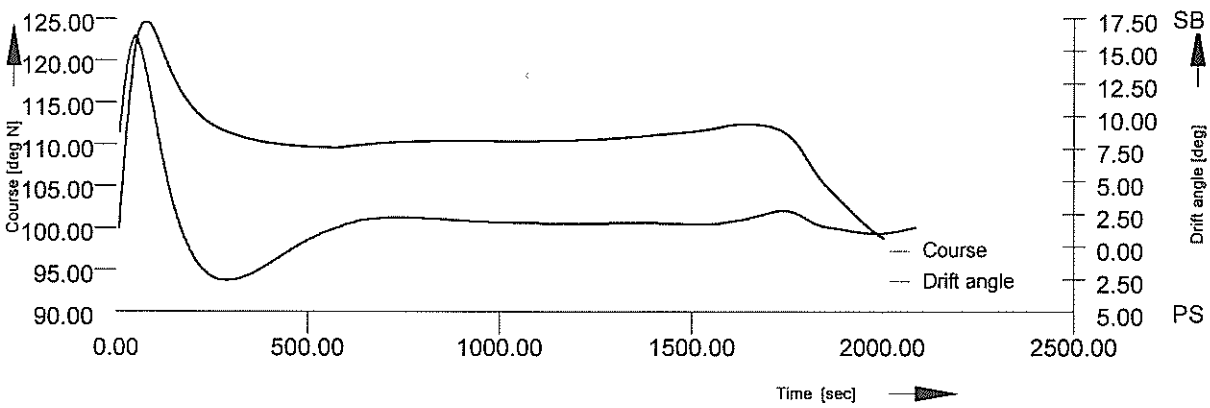
Fast time Set I.2a Condition 42		R01
		W. Welvaarts
		June 2001
AVV Transport Research Centre	B010	

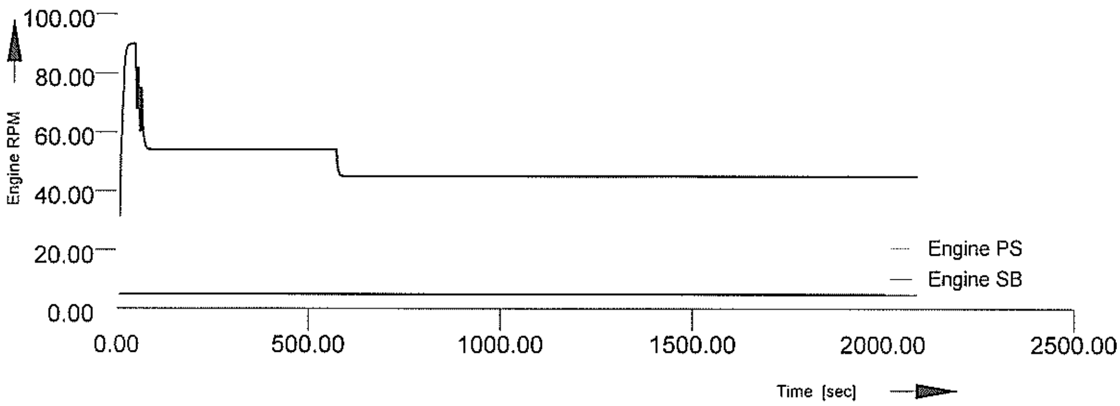
Alkyon 6/22/01 1:27:32 AM

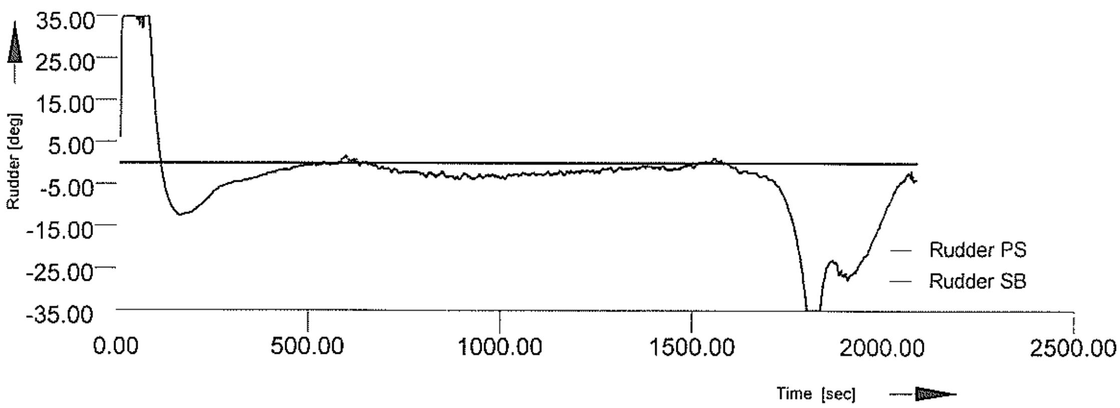


Fast time Set I.2a Condition 44	R03 W. Welvaarts June 2001
AVV Transport Research Centre B010	



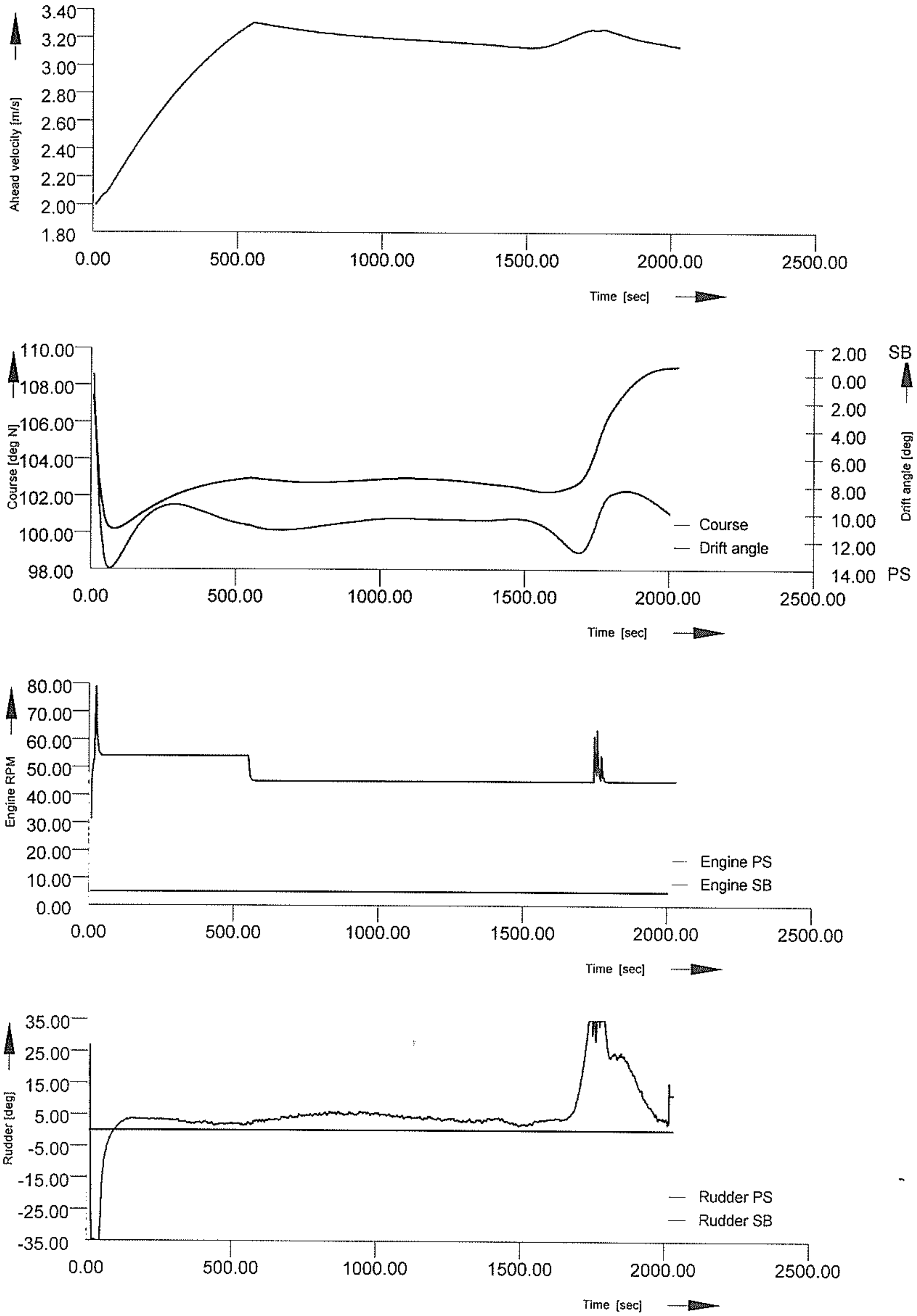




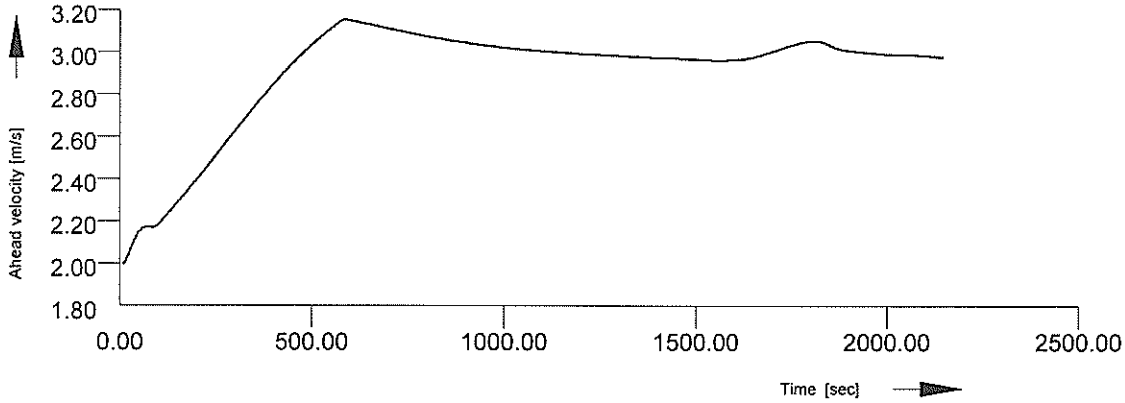


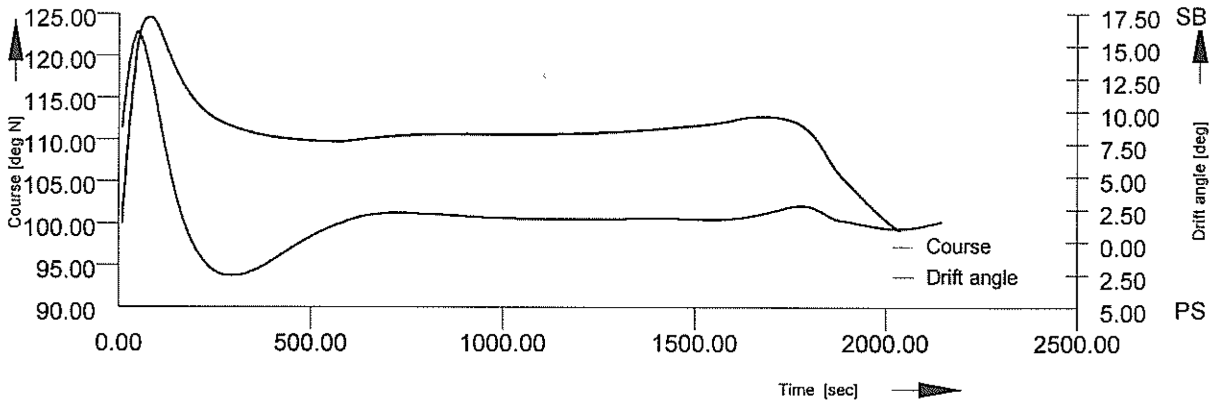
Fast time Set I.2a Condition 45	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

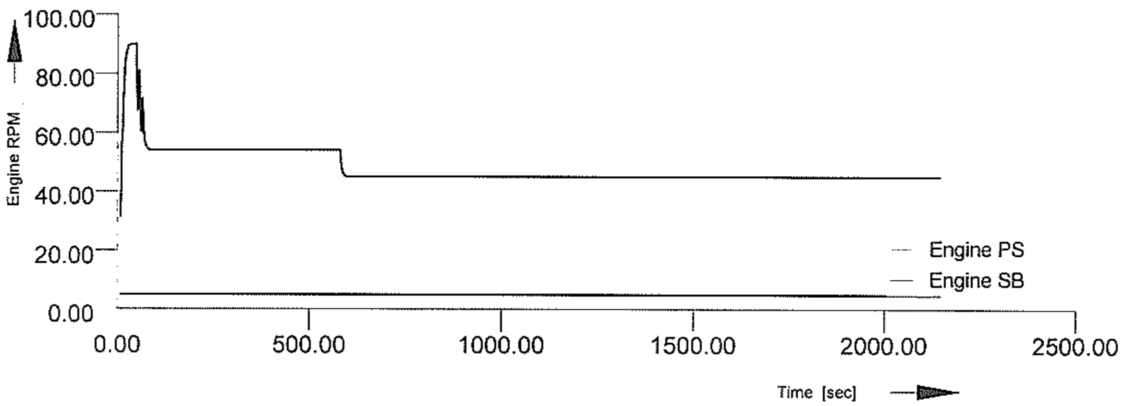
Alkyon 6/22/01 1:31:30 AM

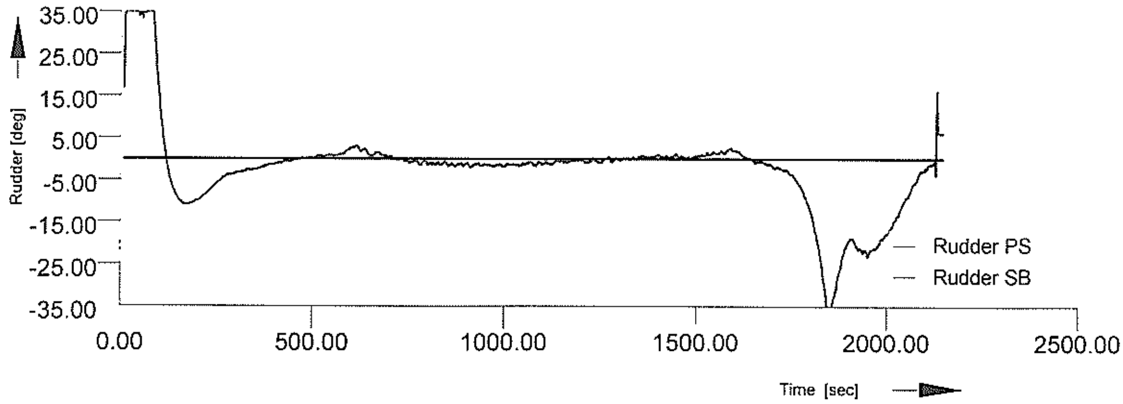


Fast time Set I.2a Condition 50		R01
		W. Welvaarts
		June 2001
AVV Transport Research Centre	B010	





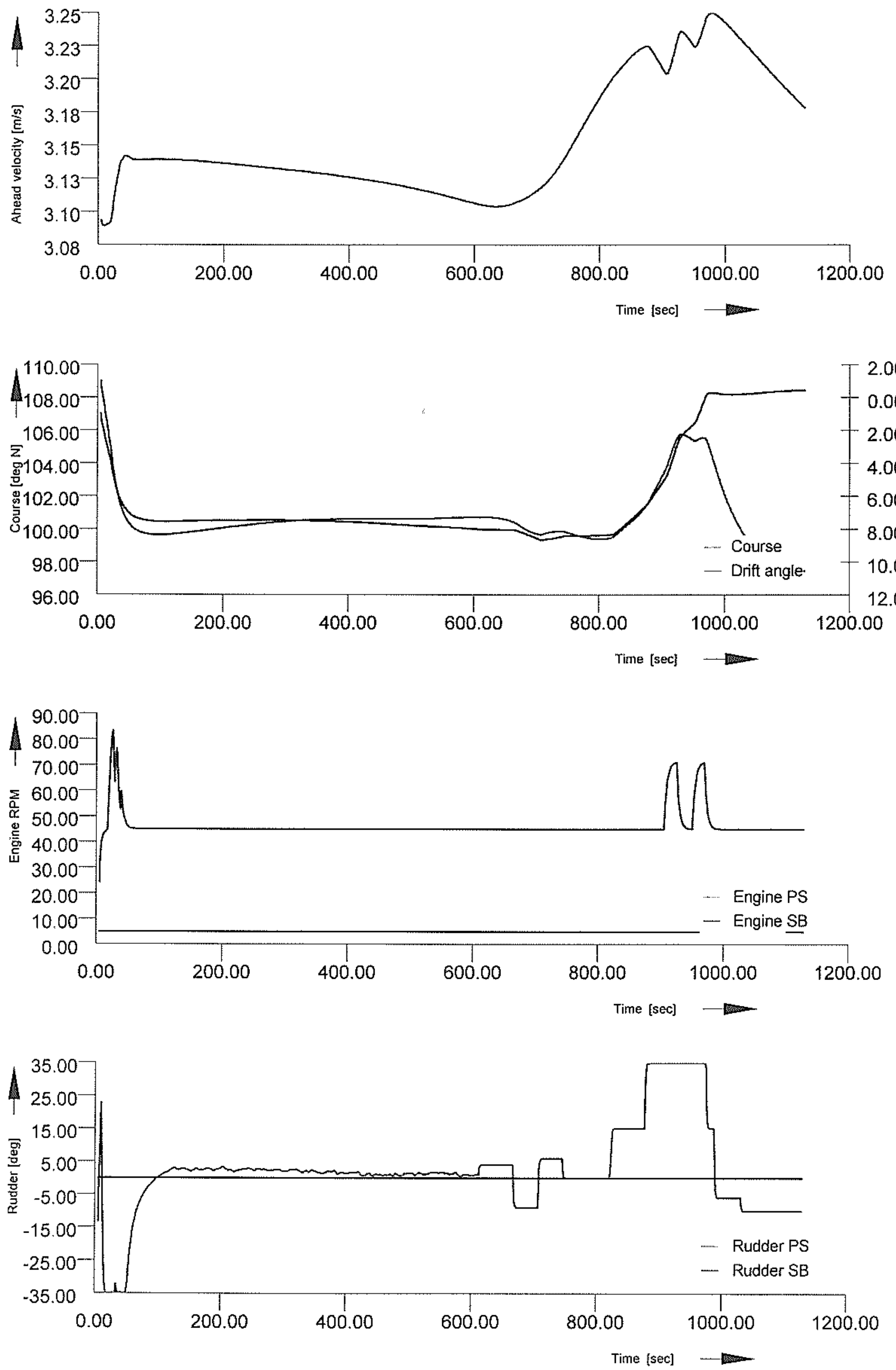




Fast time Set I.2a Condition 51	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	

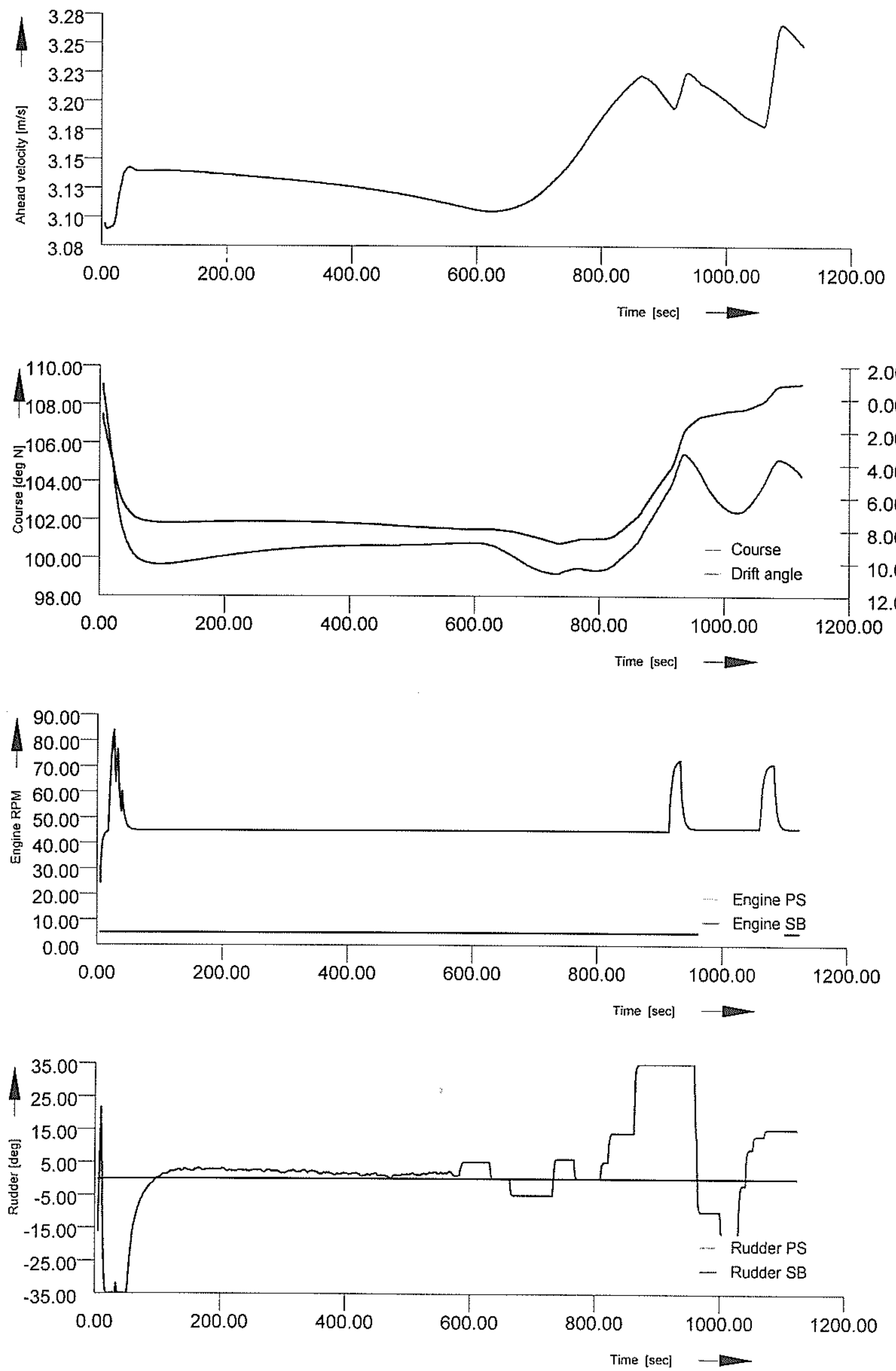
Appendix XVI.2: Real time runs condition 26

Alkyon 6/22/01 1:34 06 AM



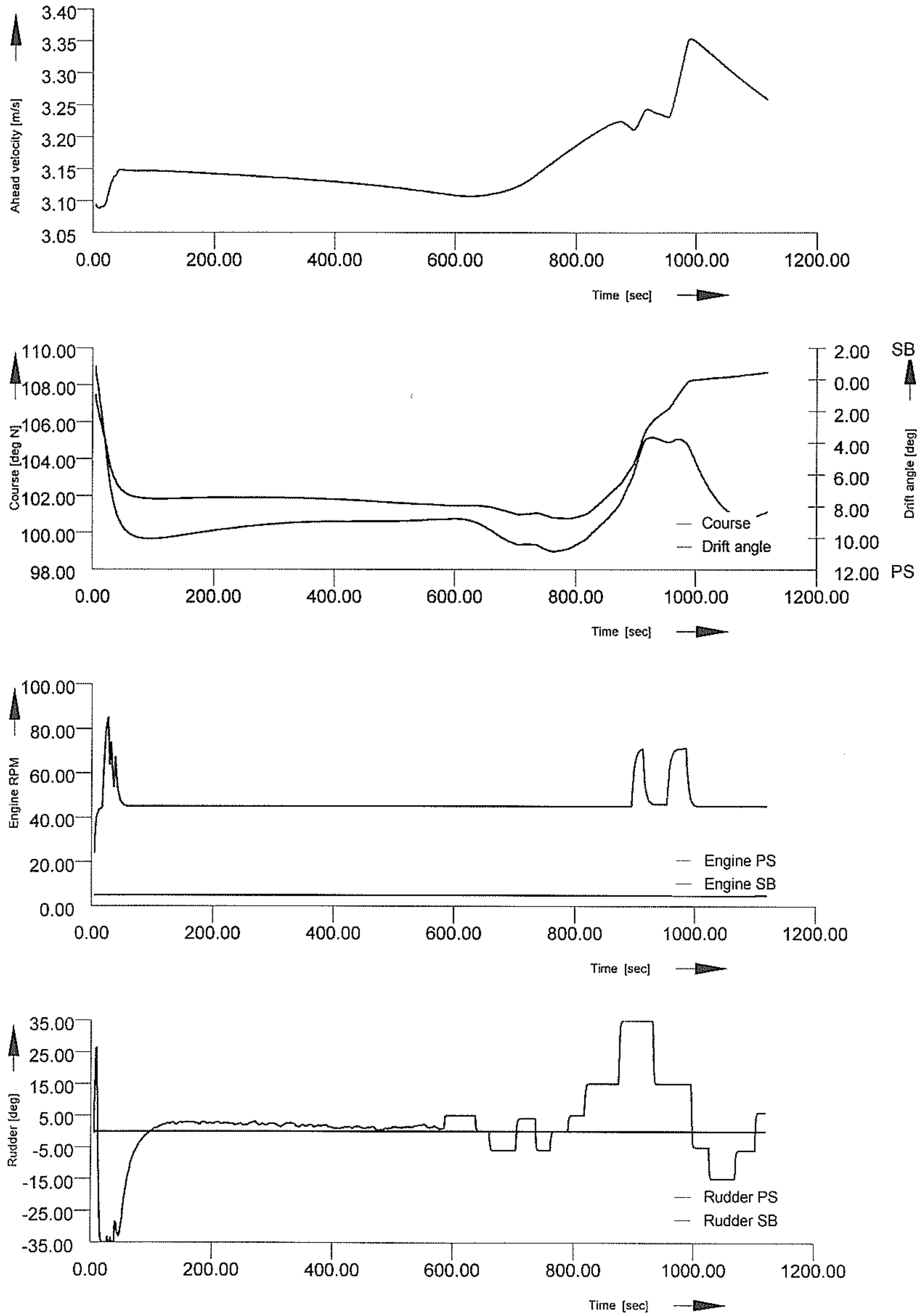
Real time Set I.2a Condition 26	R01	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

Alkyon 6/22/01 1:42:51 AM



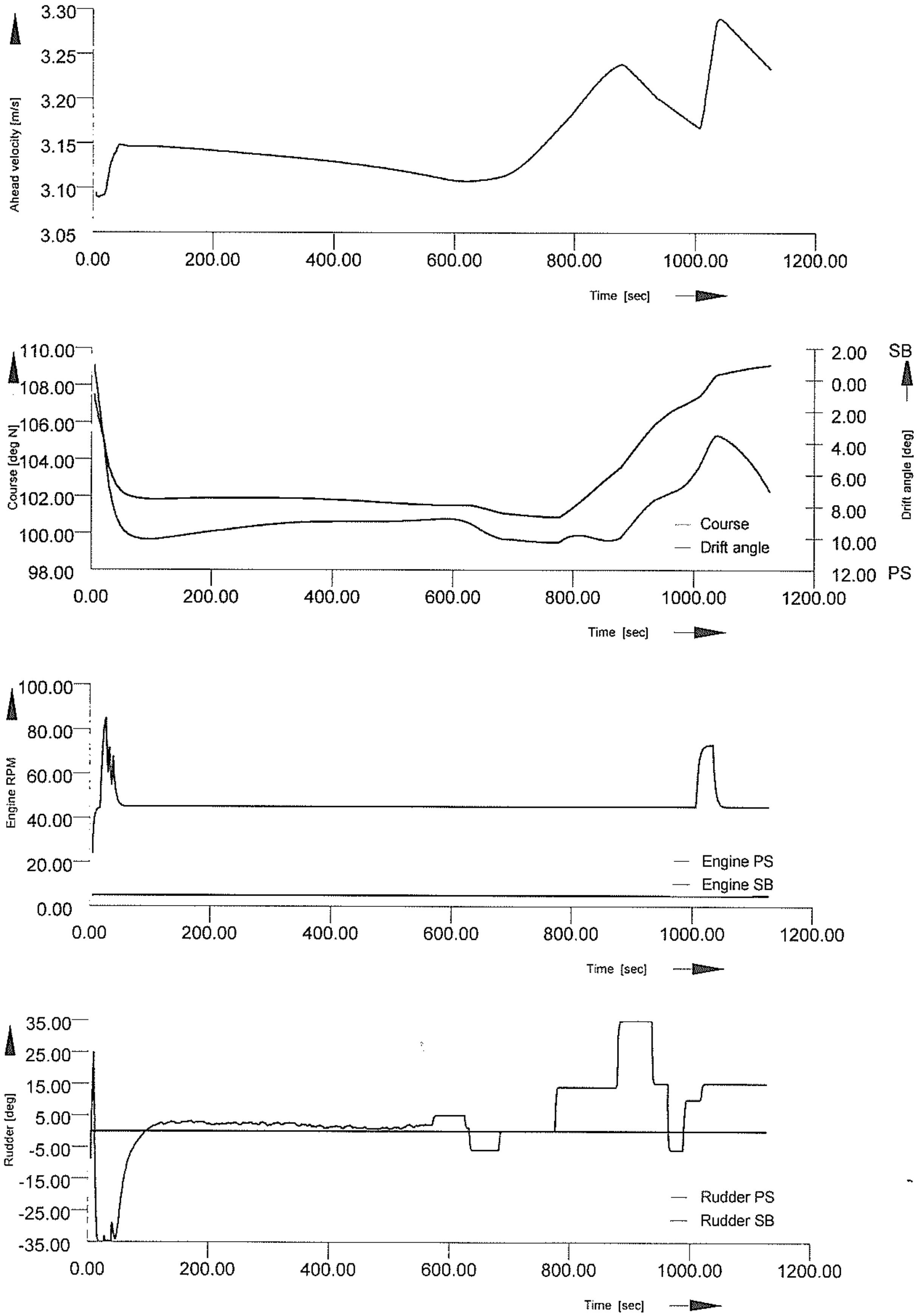
Real time	R02	
Set I.2a	W. Welvaarts	
Condition 26	June 2001	
AVV Transport Research Centre B010		

Alkyon 6/22/01 1:43:21 AM

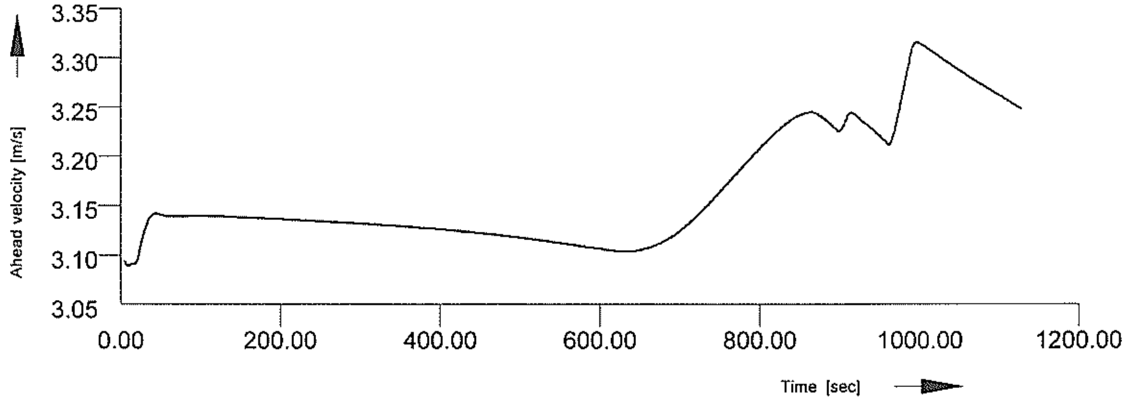


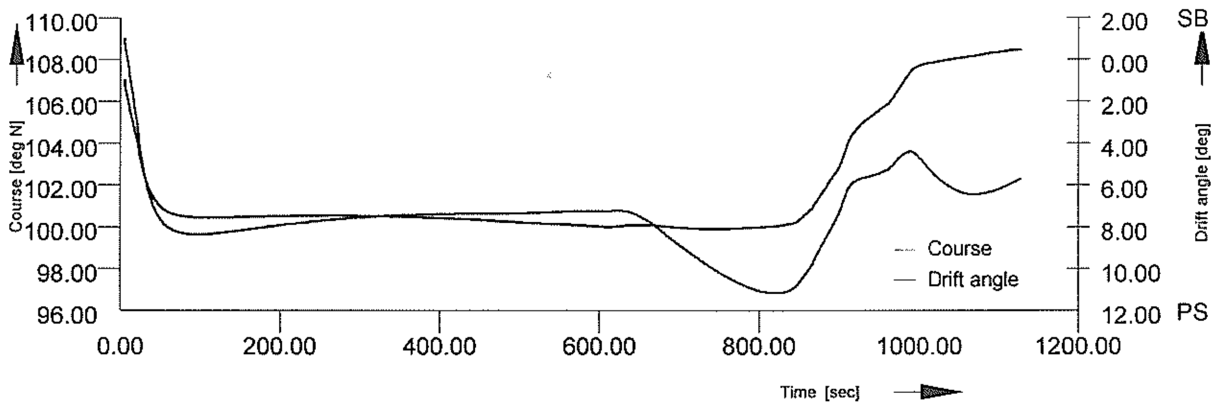
Real time Set I.2a Condition 26	R03 W. Welvaarts June 2001
AVV Transport Research Centre B010	

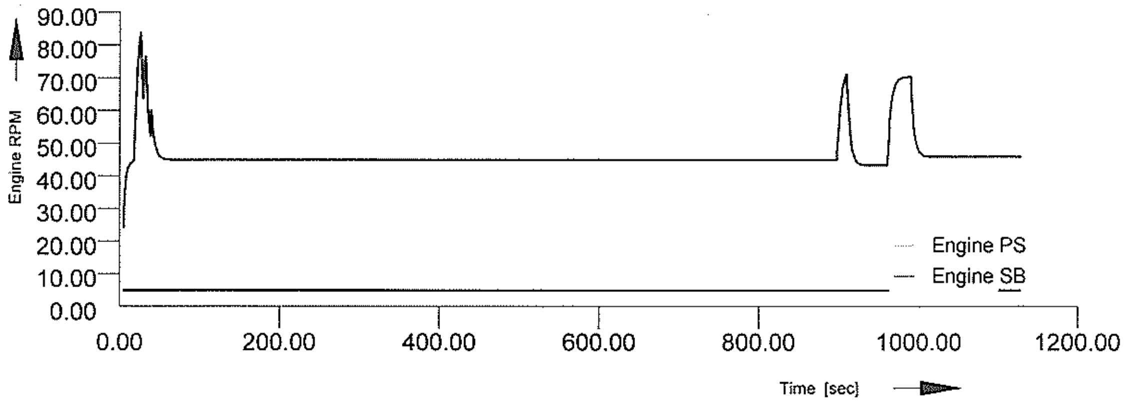
Alkyon 6/22/01 1:44:00 AM

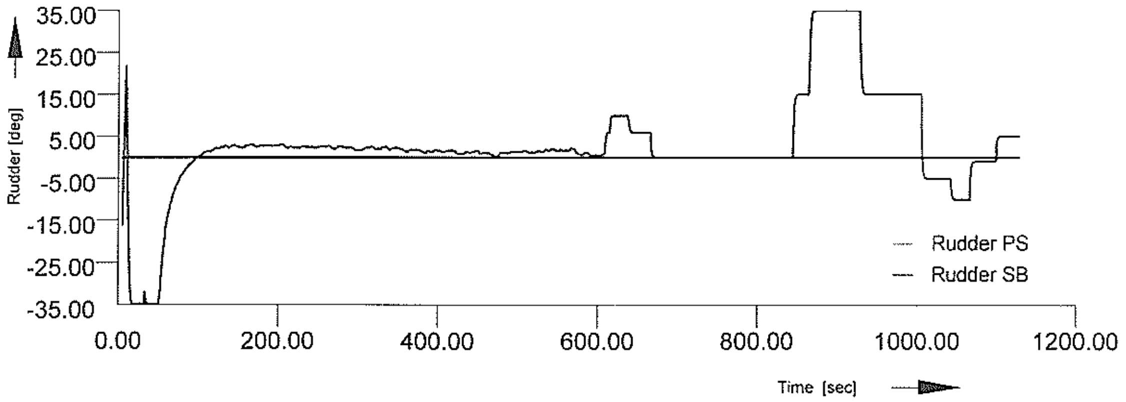


Real time Set I.2a Condition 26	R05 W. Welvaarts June 2001
AVV Transport Research Centre B010	

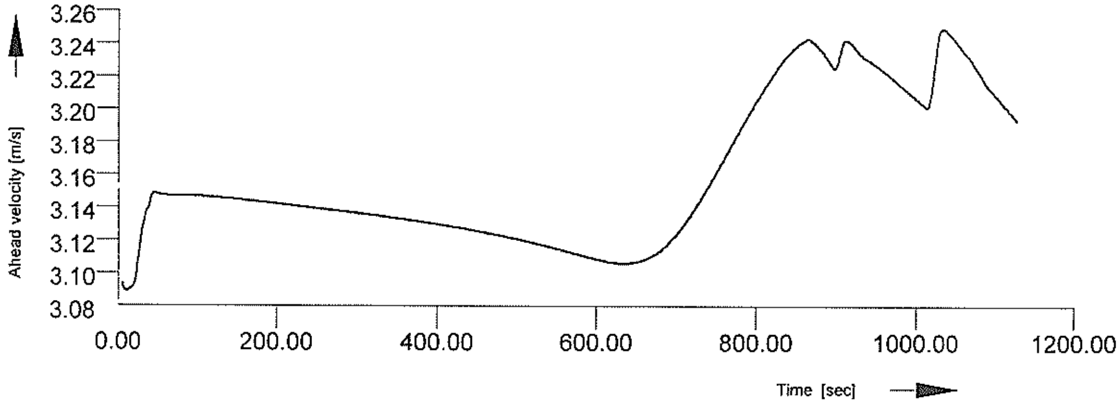


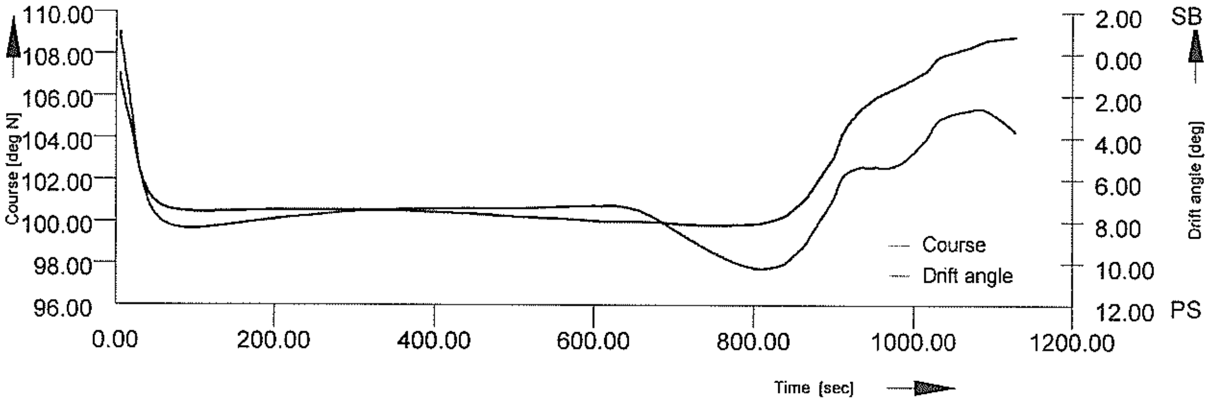


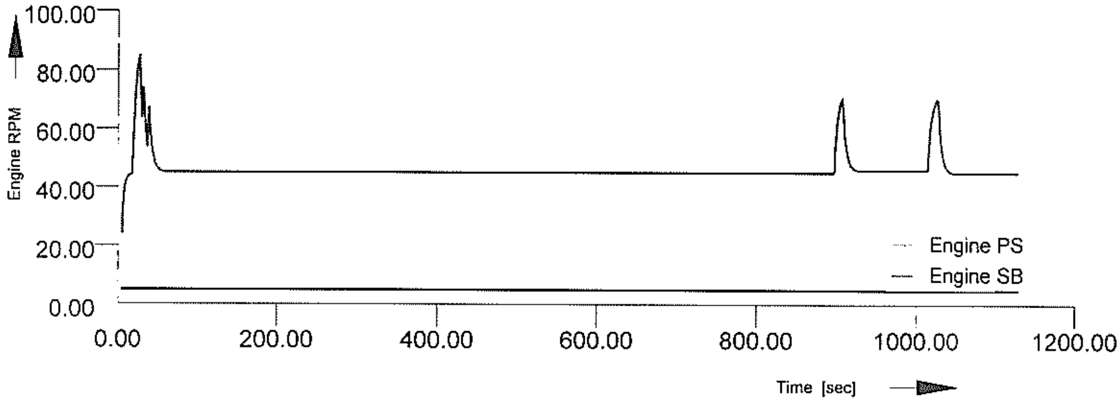


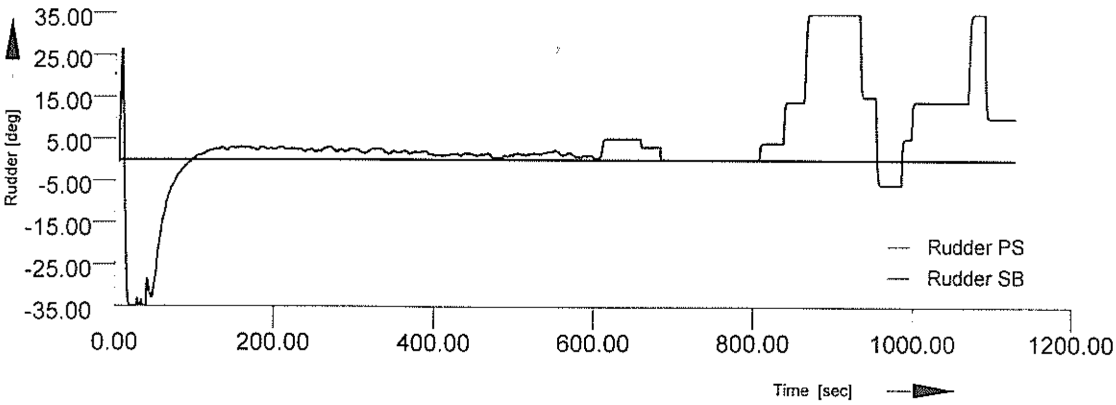


Real time Set I.2a Condition 26	R08	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	



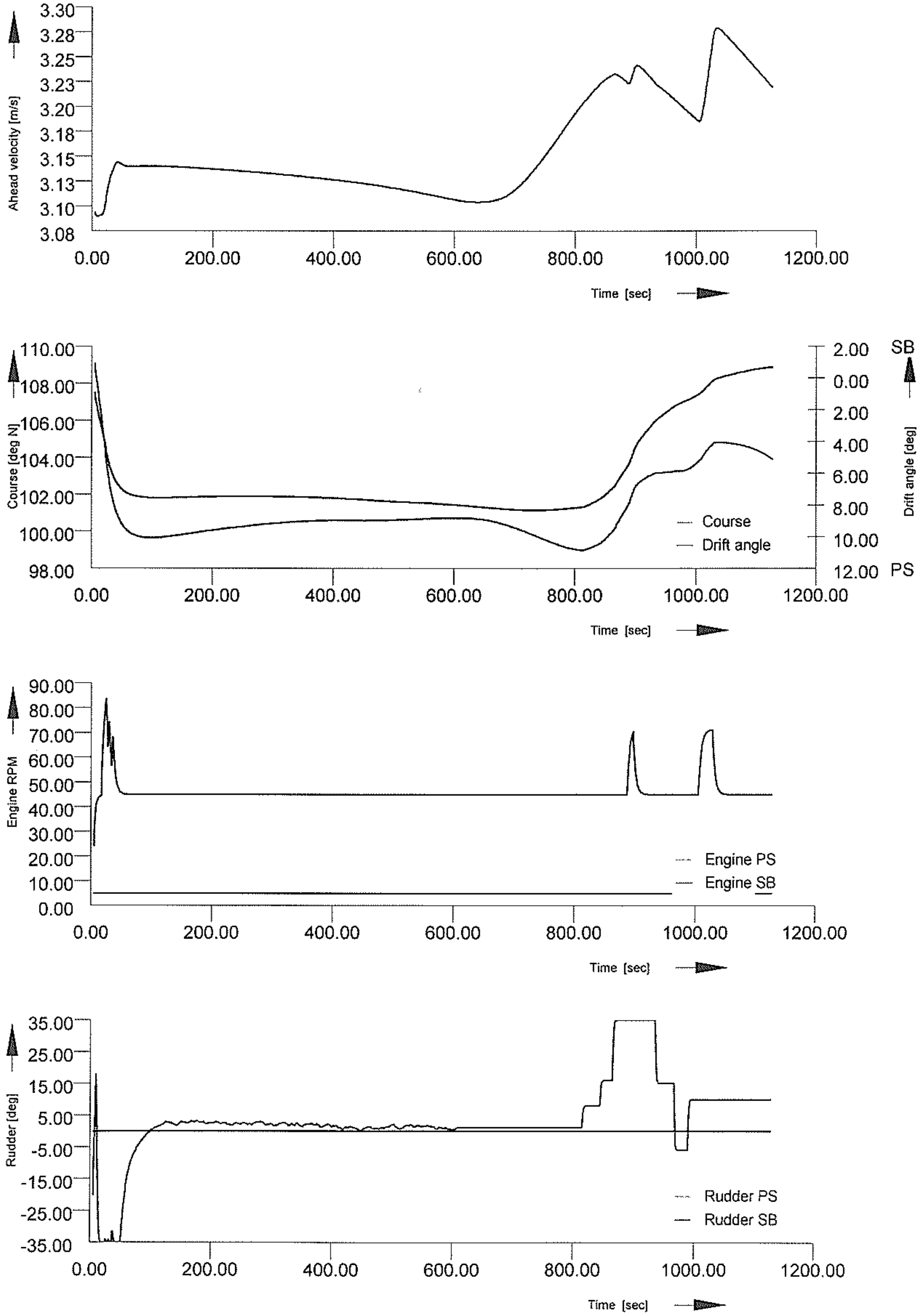






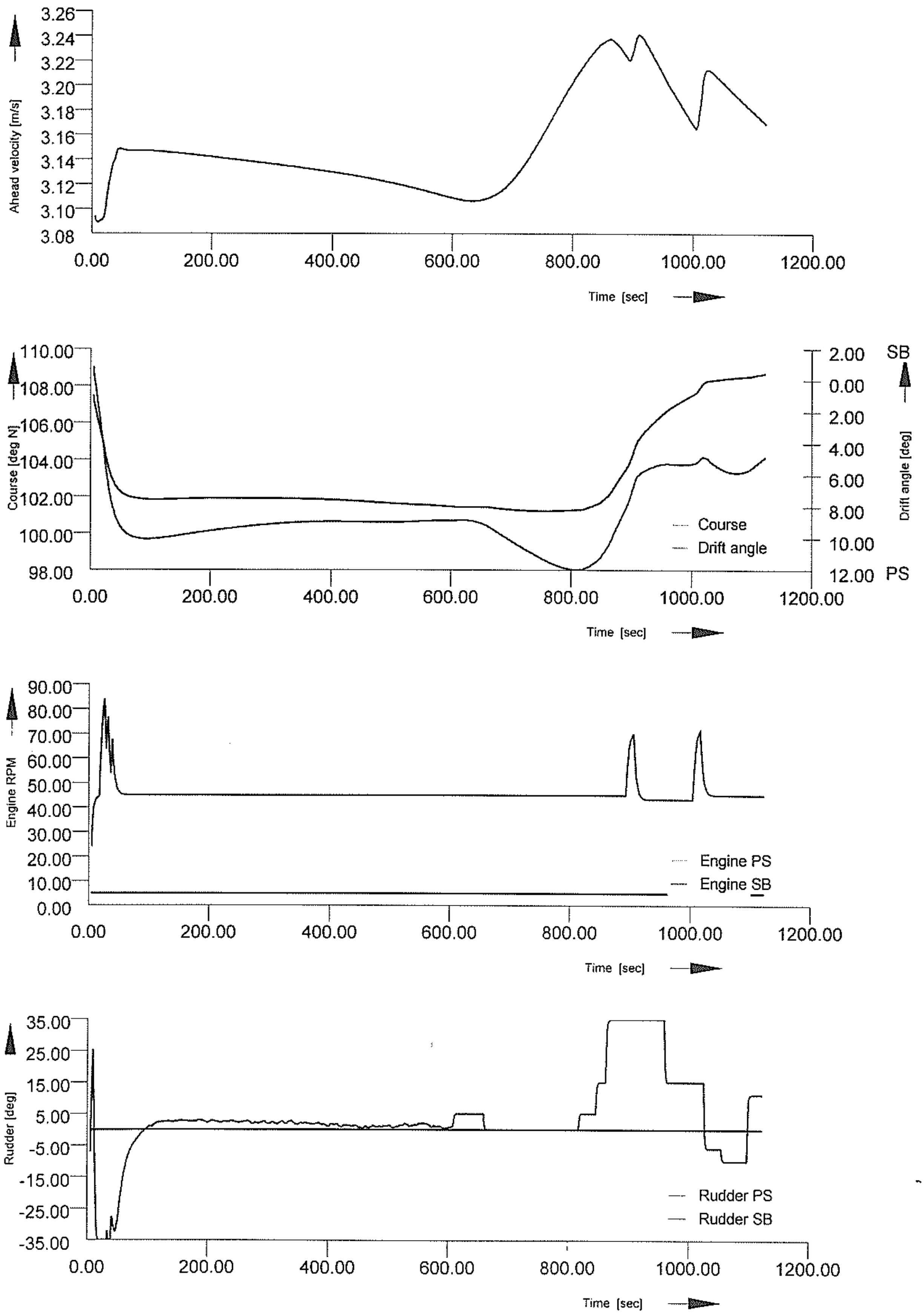
Real time Set I.2a Condition 26	R11 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 1:46:25 AM

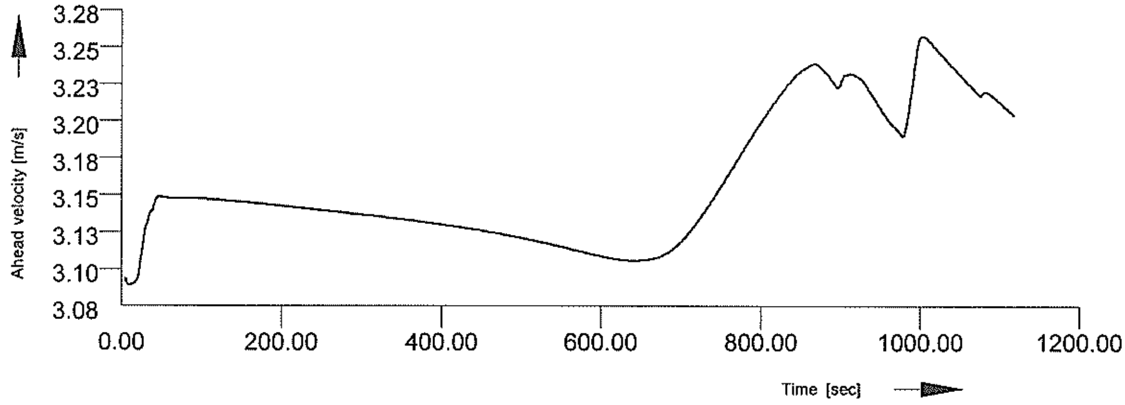


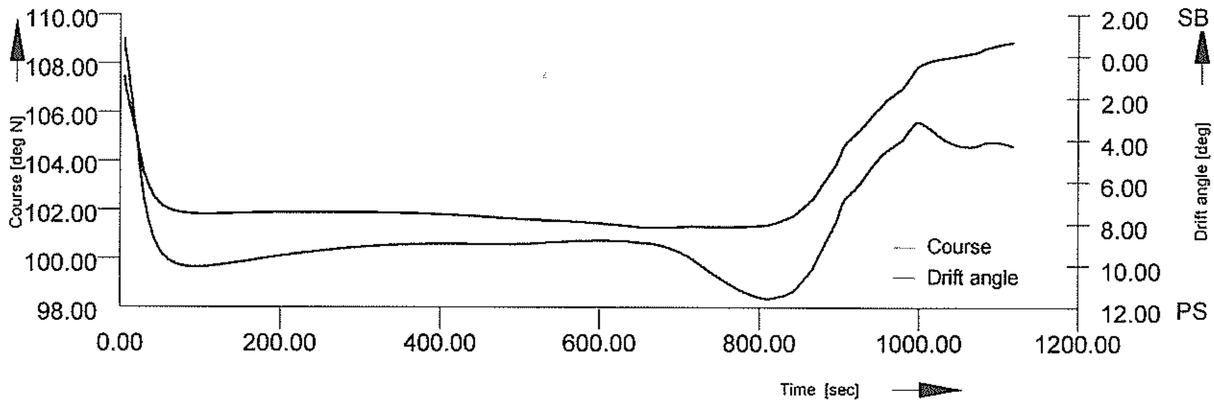
Real time Set I.2a Condition 26	R13 W. Welvaarts June 2001
AVV Transport Research Centre B010	

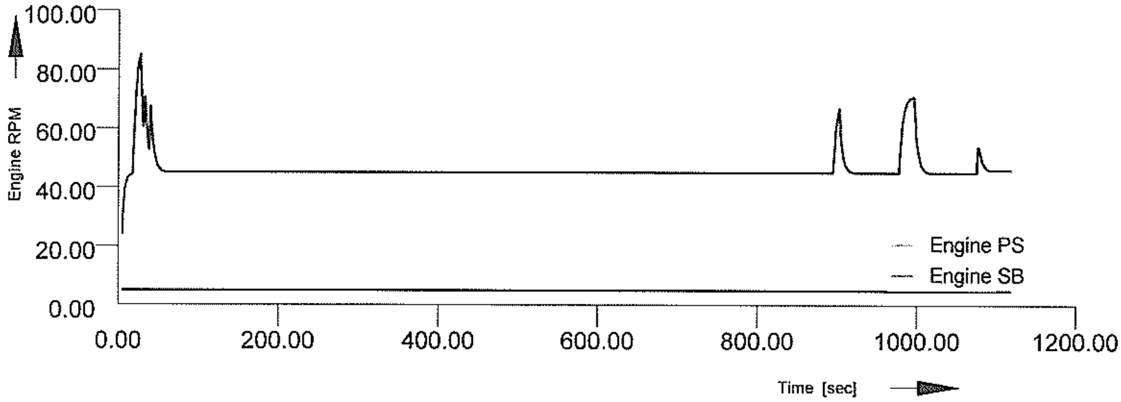
Alkyon 6/22/01 1:44:59 AM

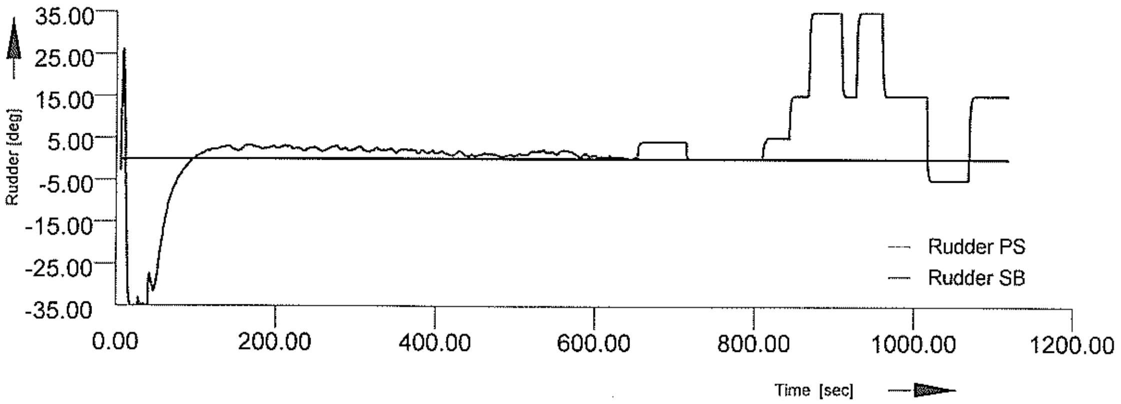


Real time Set I.2a Condition 26	R09	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

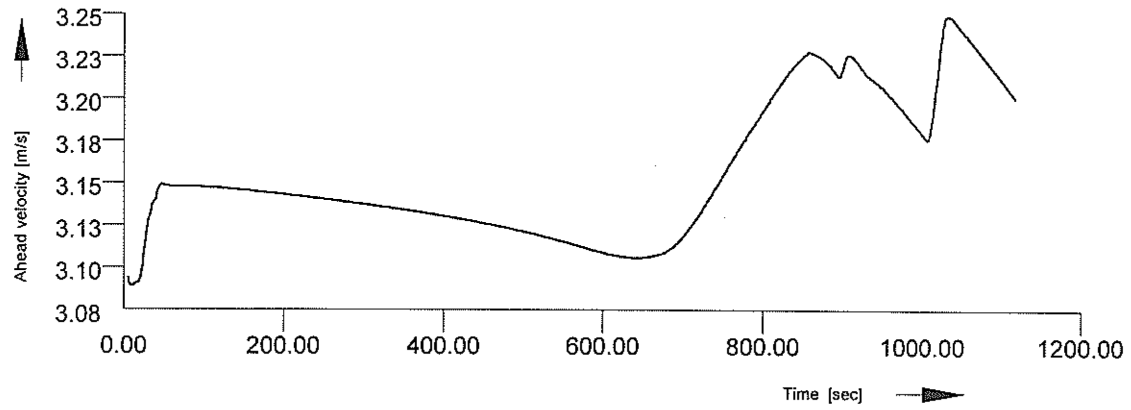


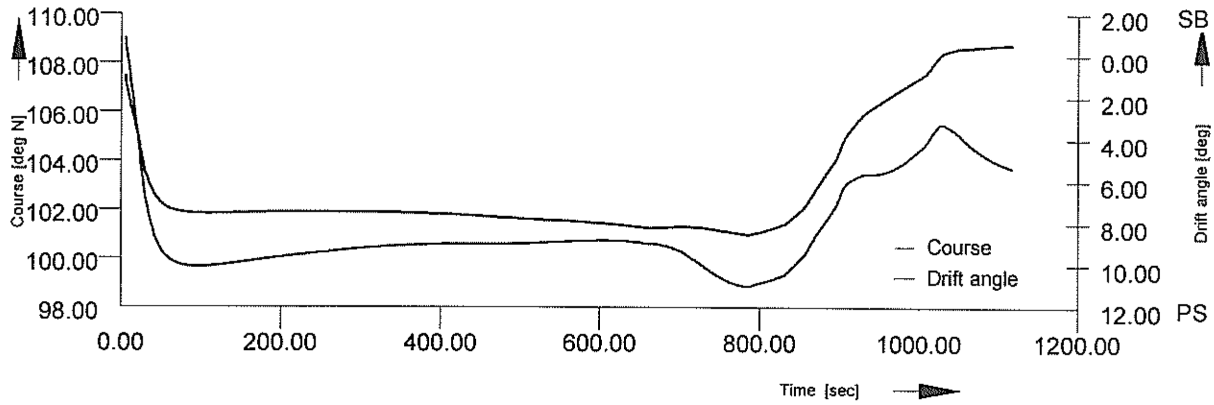


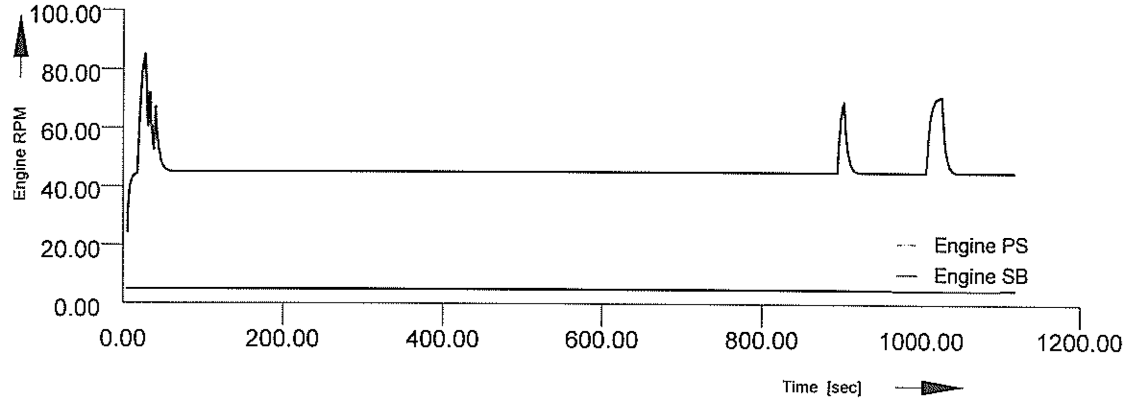


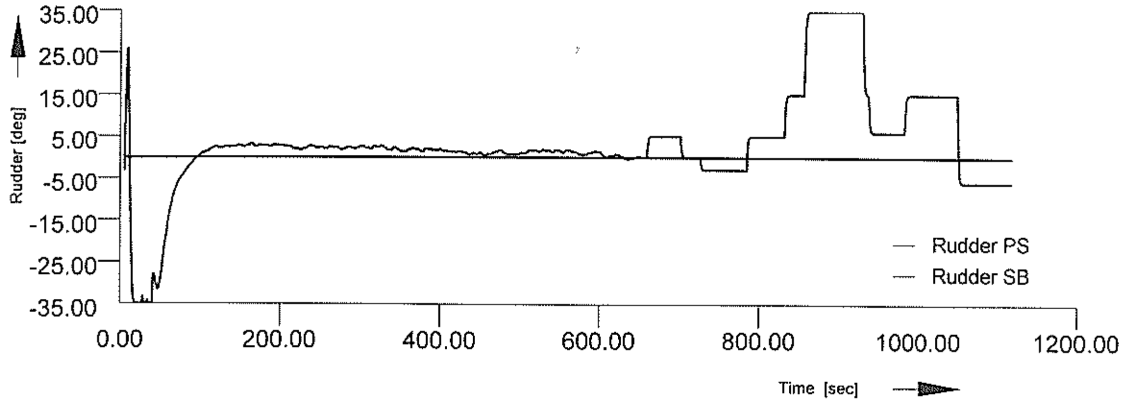


Real time Set I.2a Condition 26	R10	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

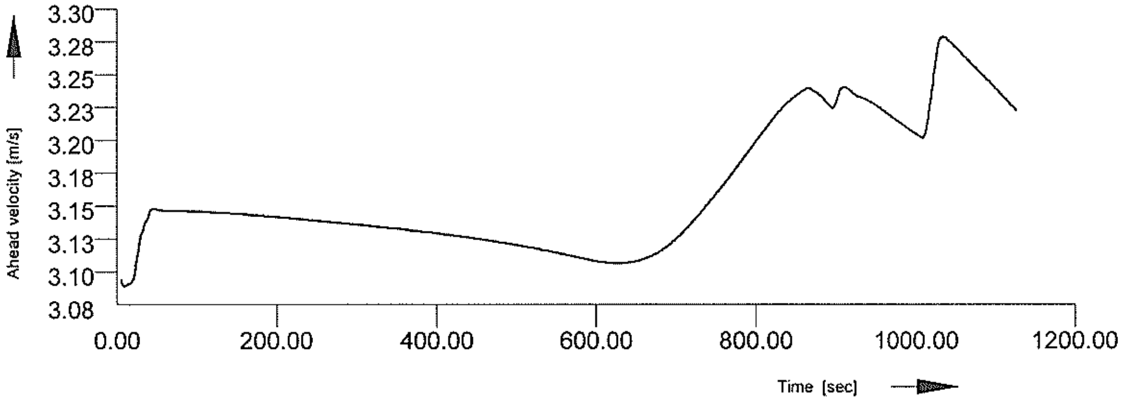


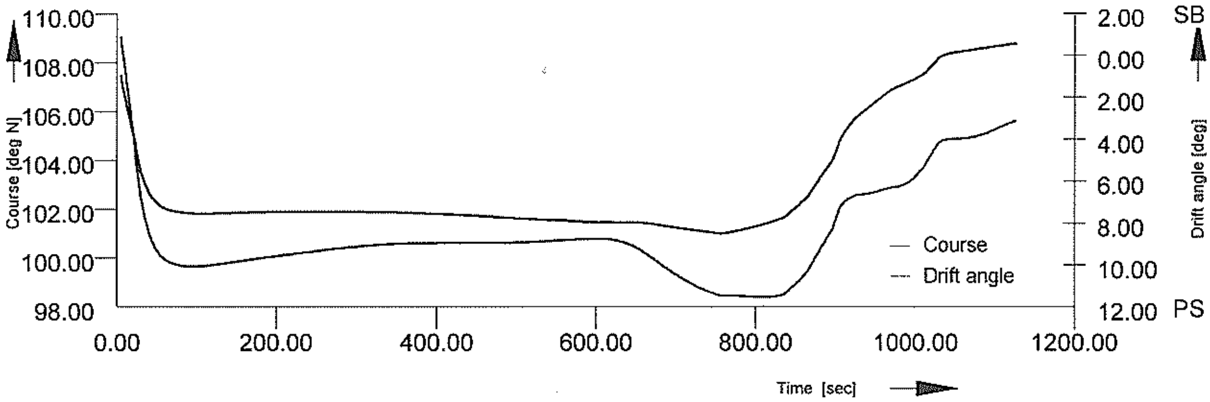


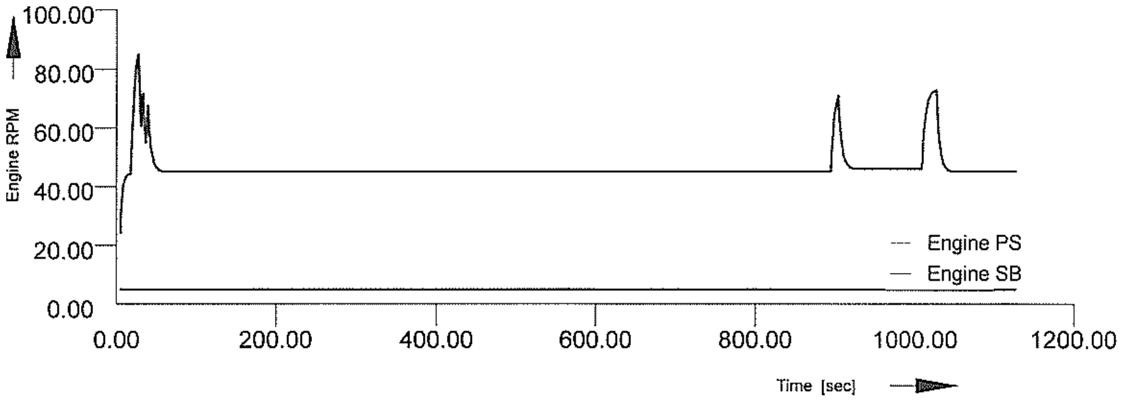


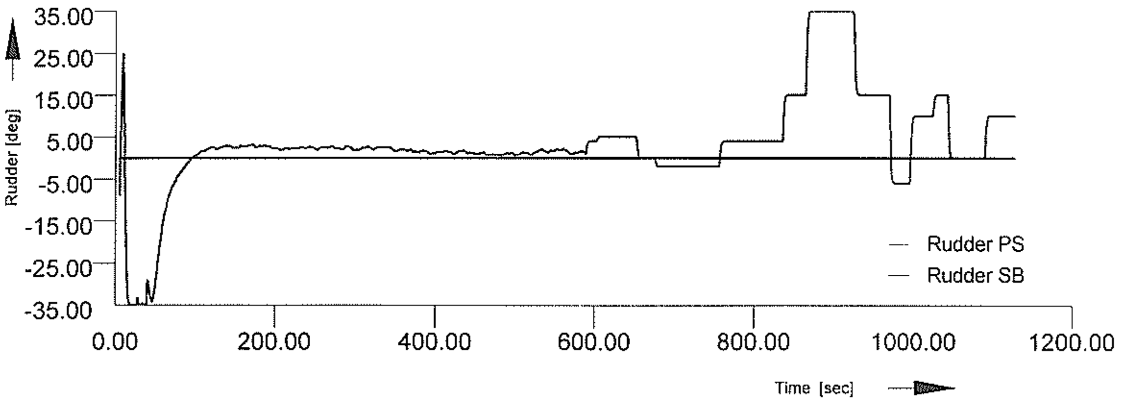


Real time Set I.2a Condition 26	R14	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

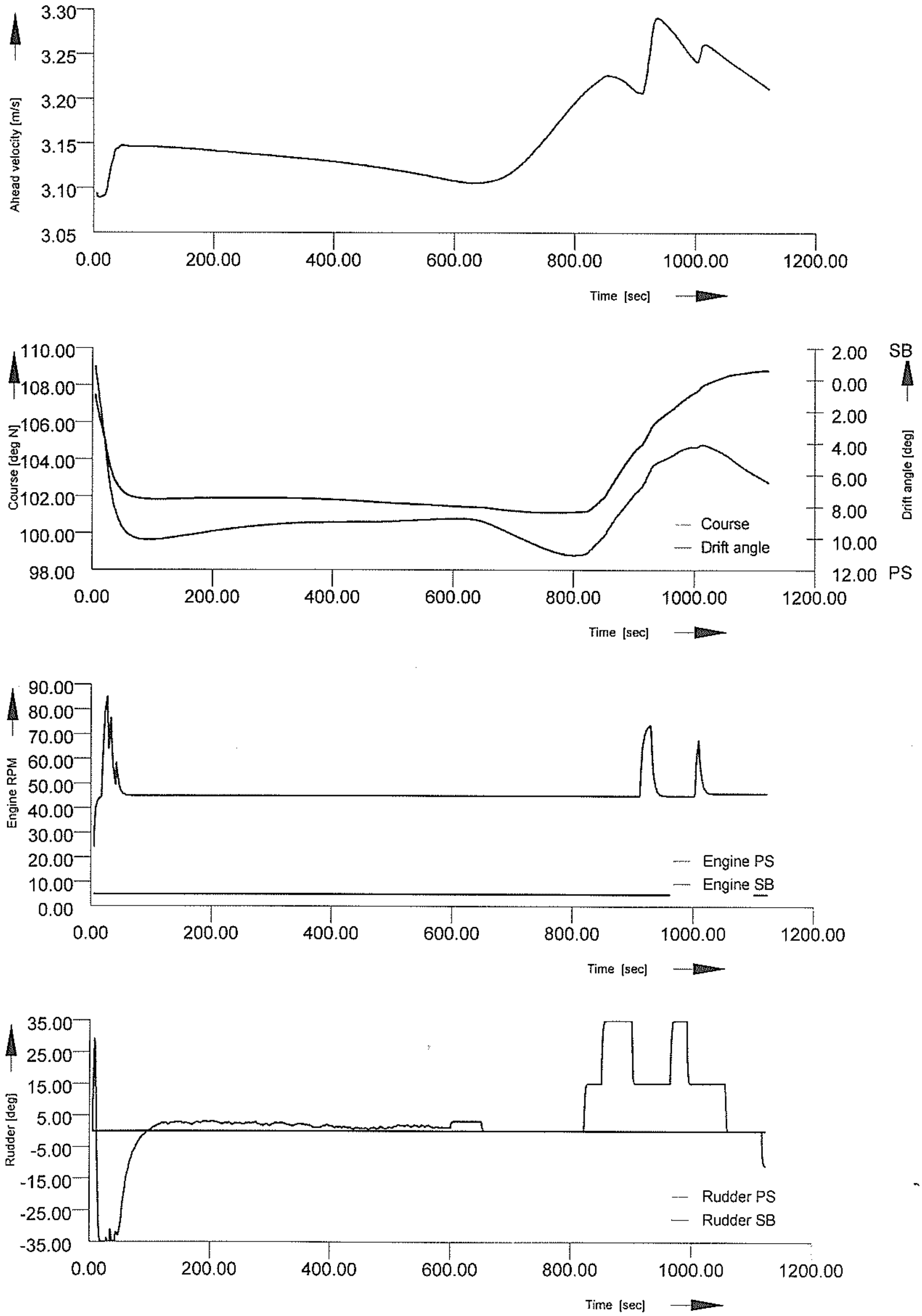






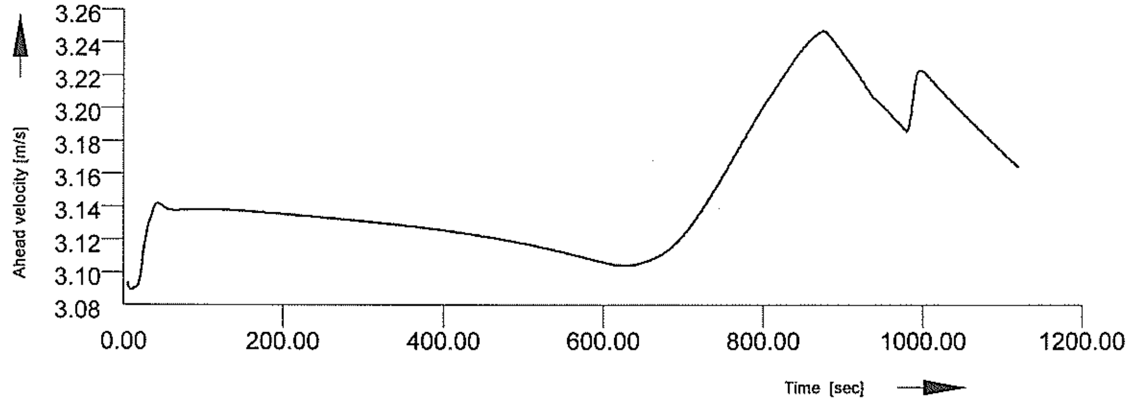


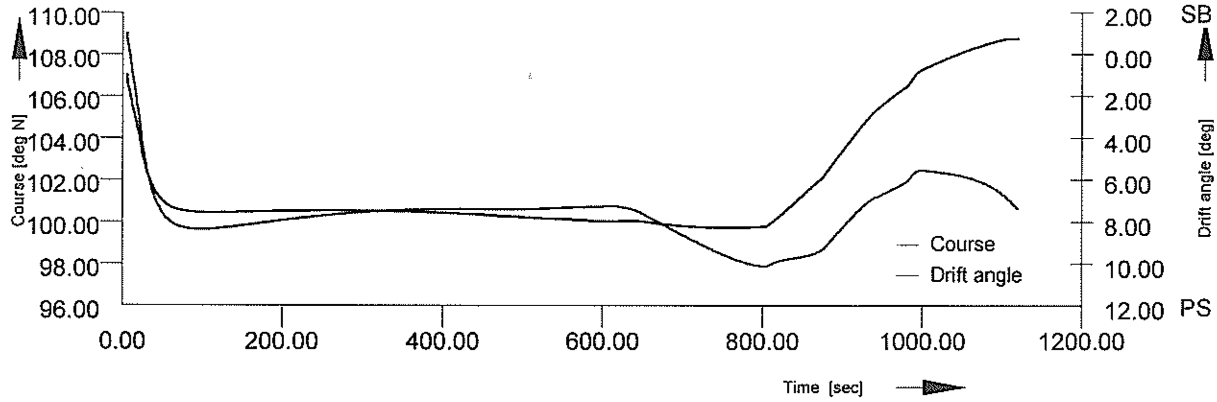
Real time Set I.2a Condition 26	R15	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

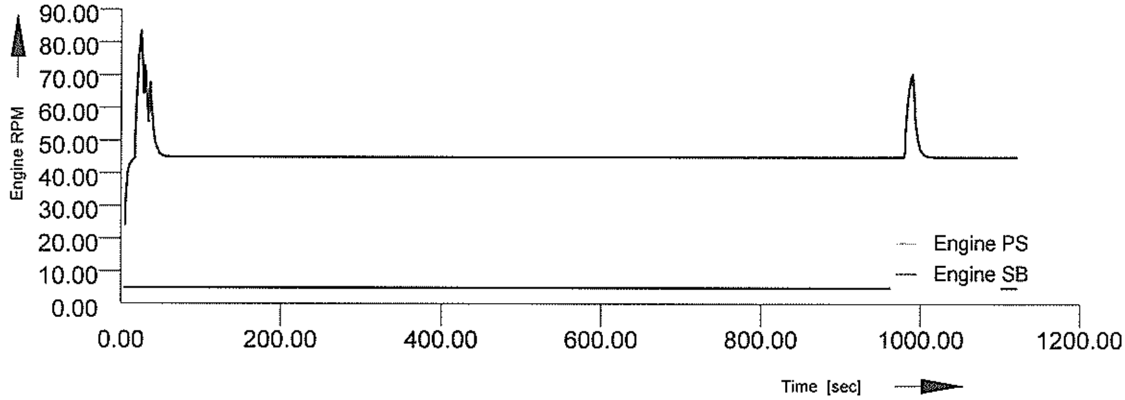


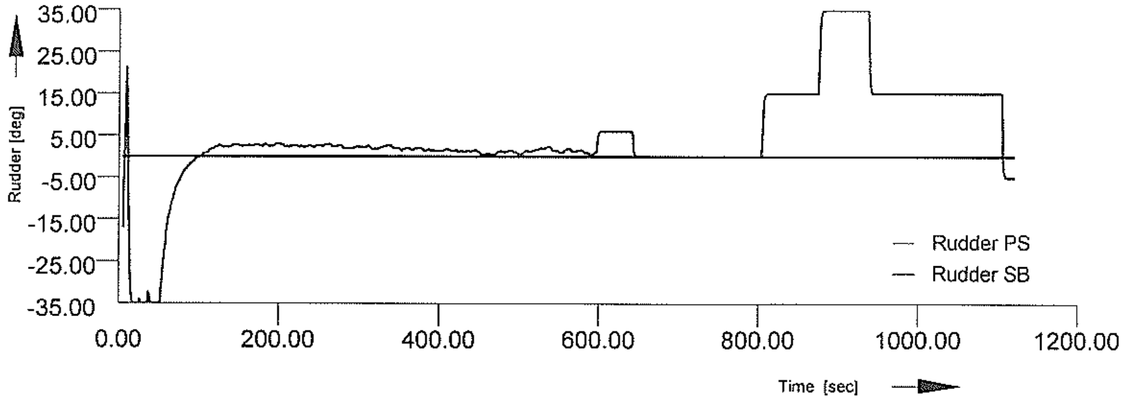
Real time Set I.2a Condition 26	R17 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 1:48:13 AM

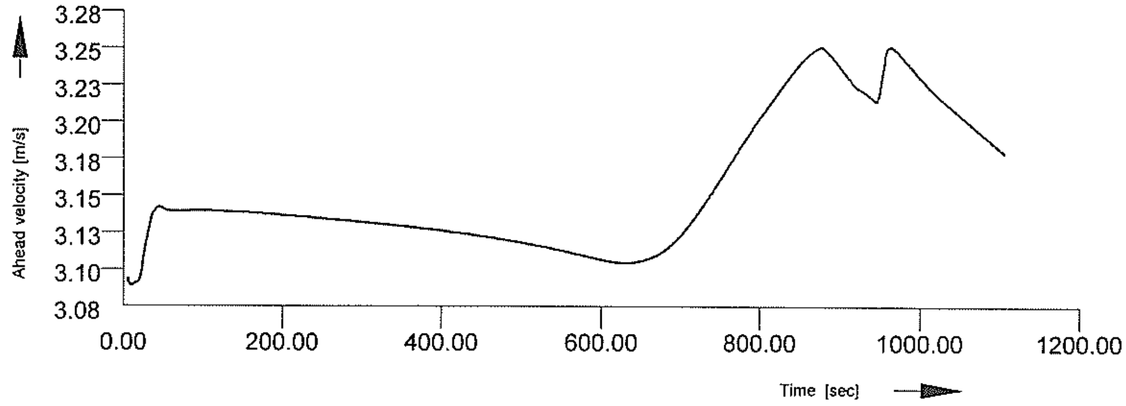


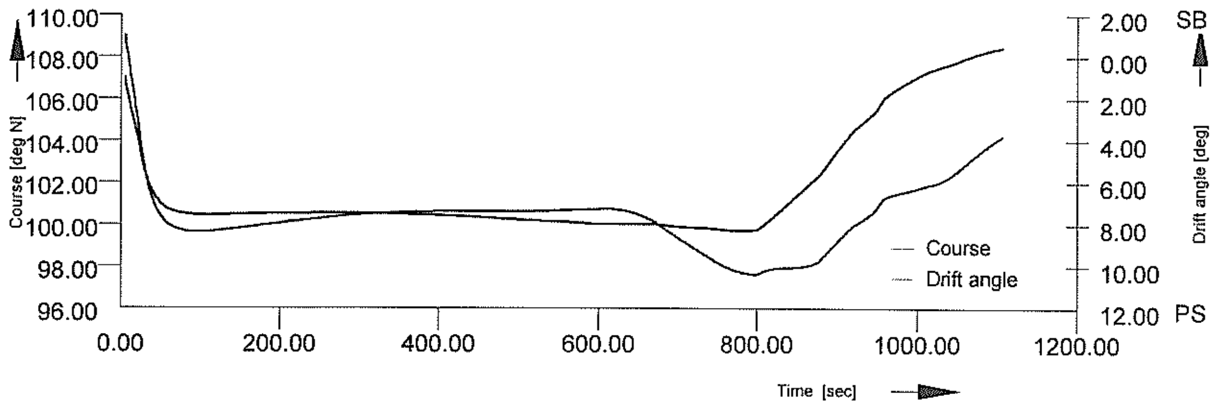


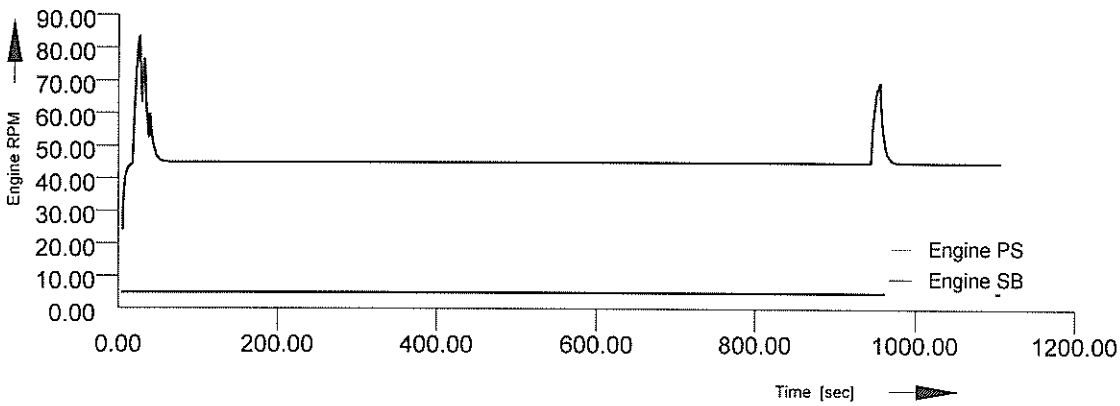


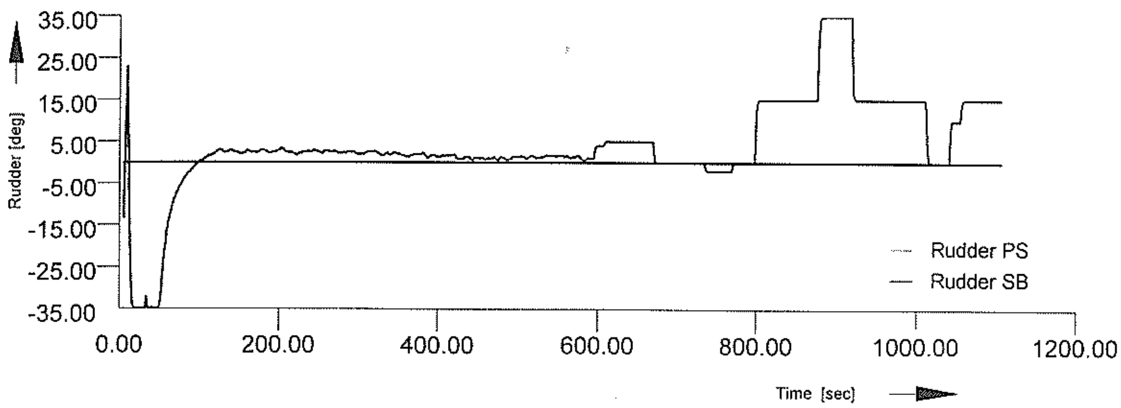


Real time Set I.2a Condition 26	R18	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

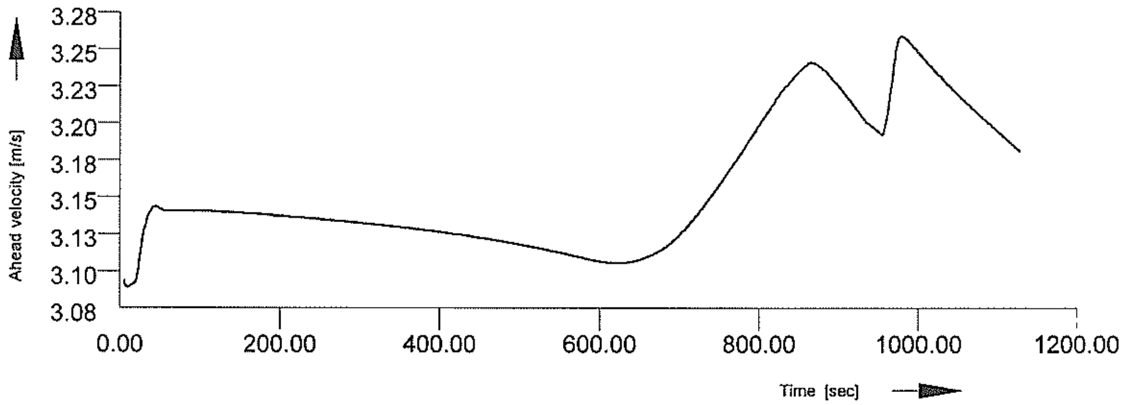


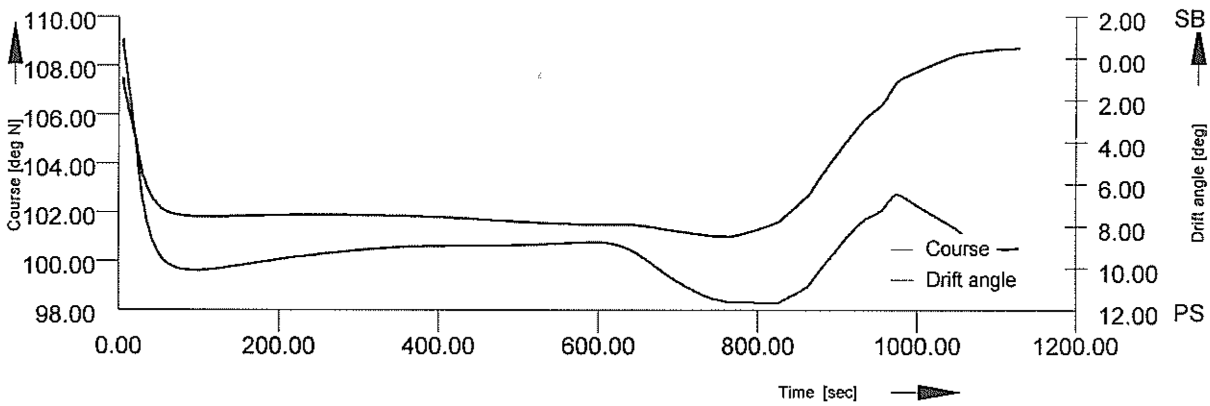


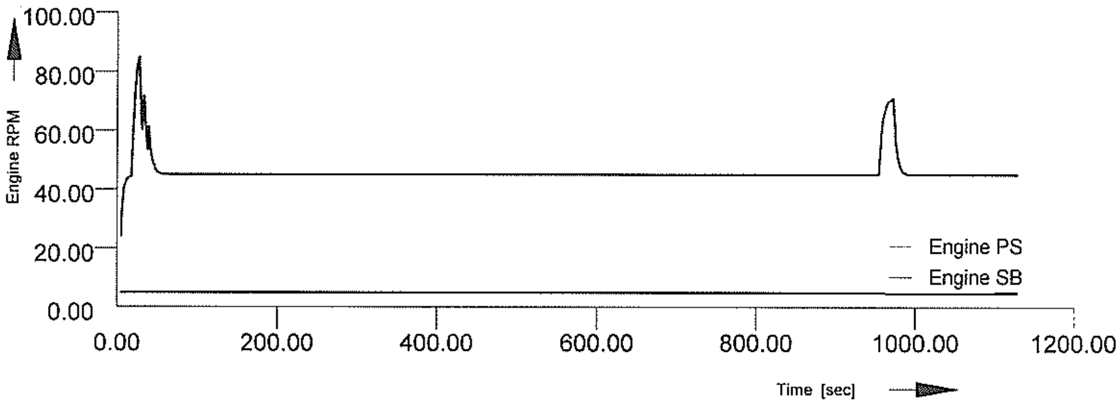


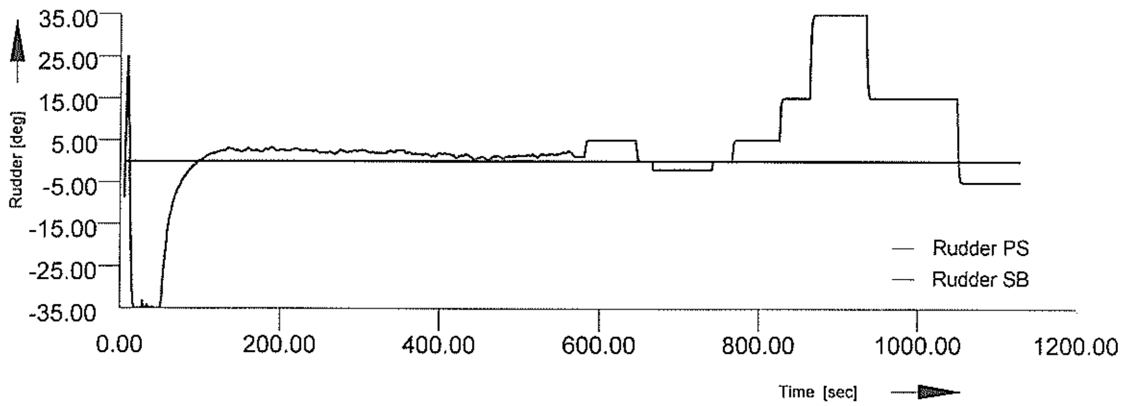


Real time Set I.2a Condition 26	R19
	W. Welvaarts
	June 2001
AVV Transport Research Centre B010	

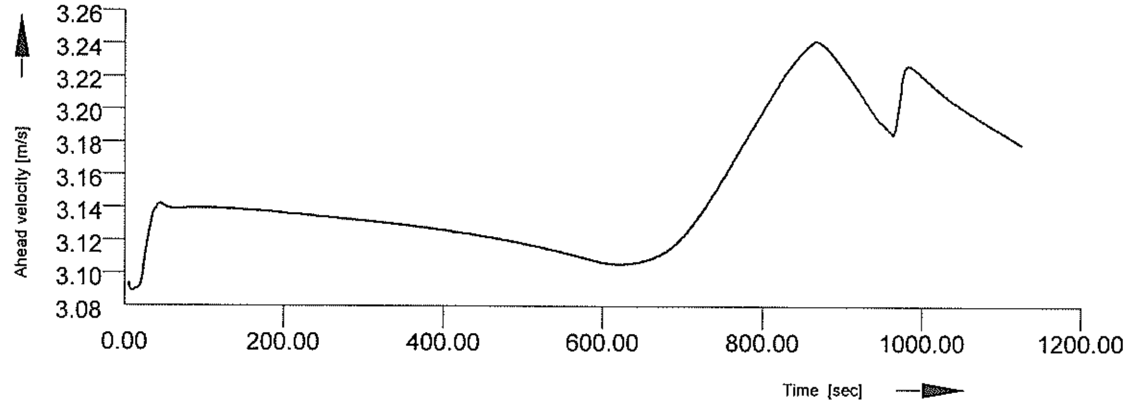


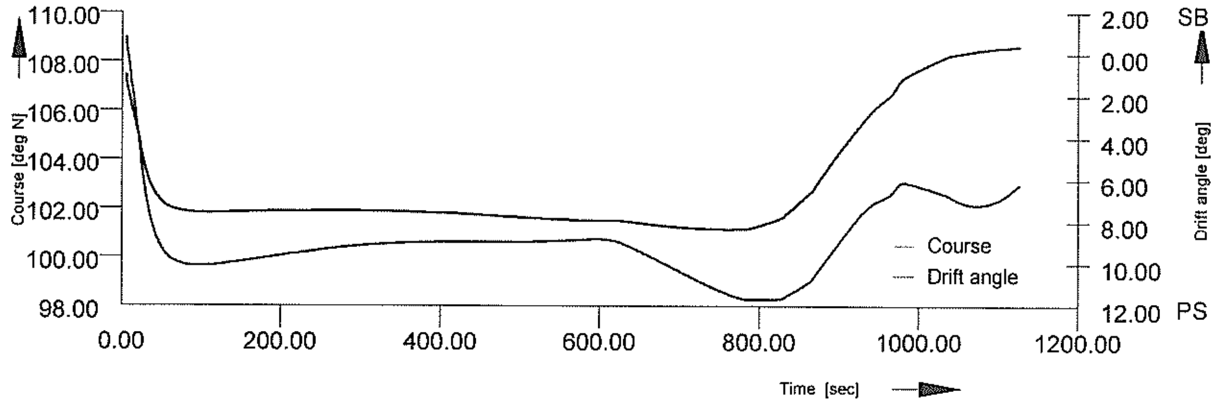


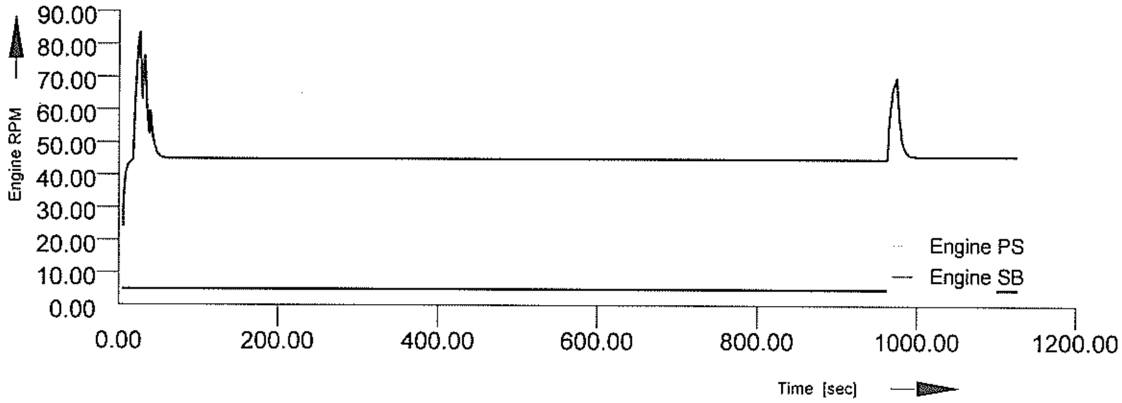


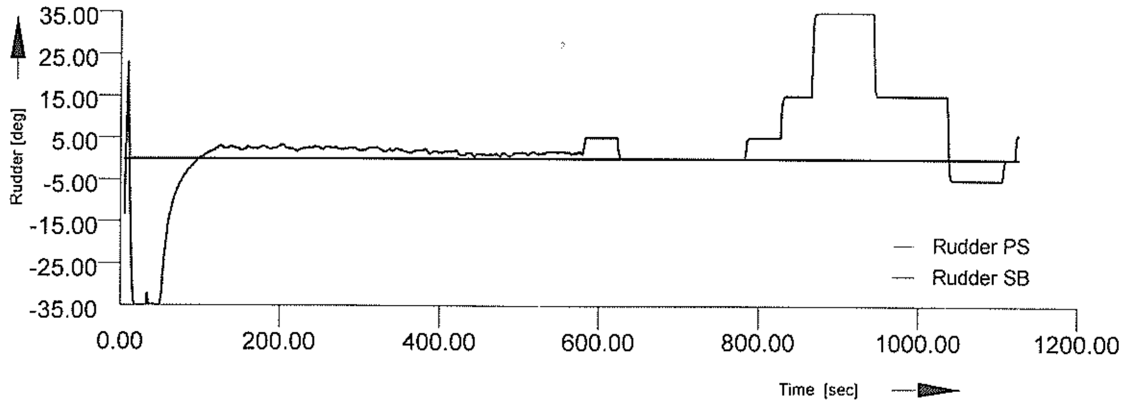


Real time Set I.2a Condition 26	R20	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	



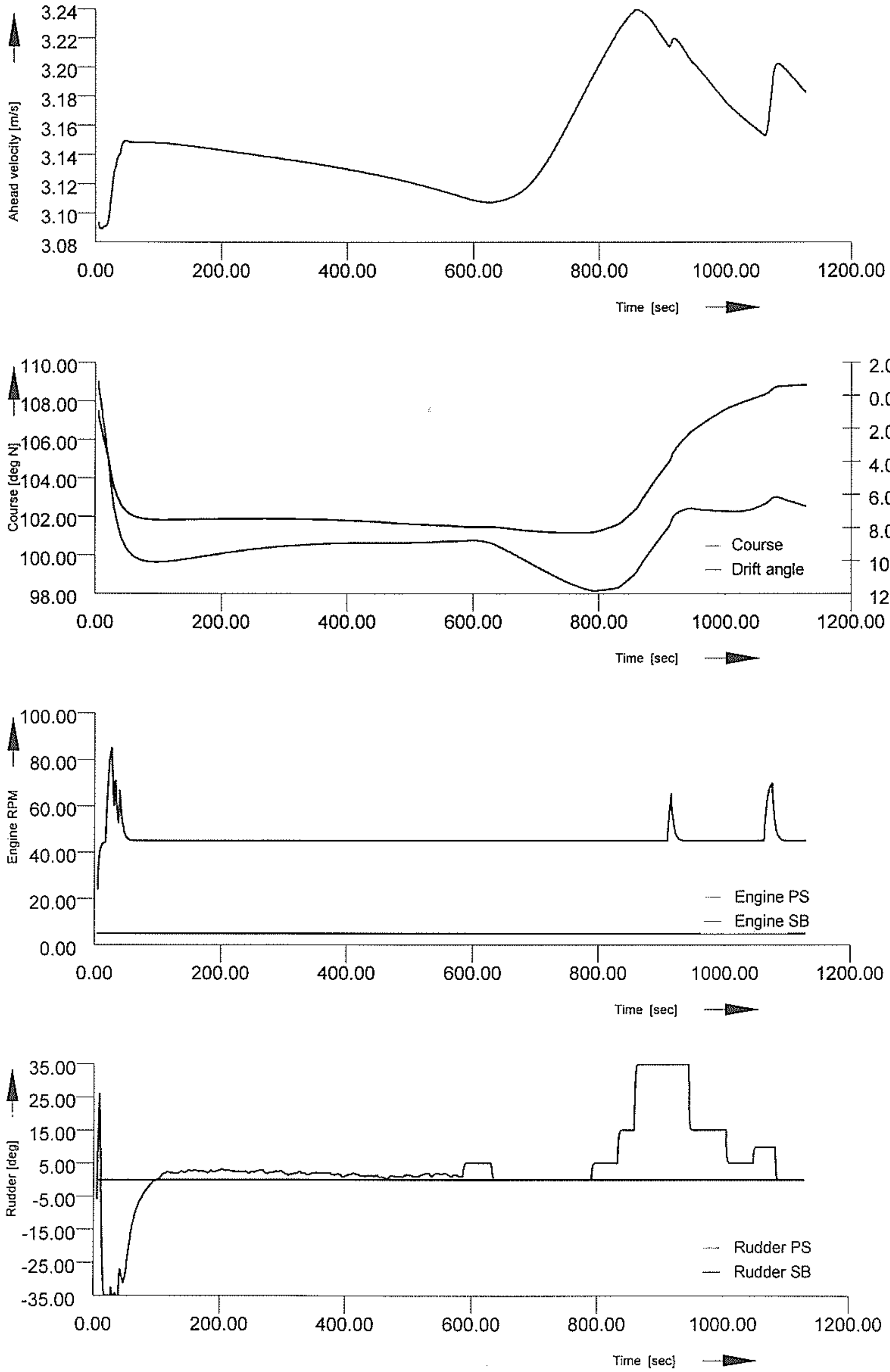






Real time Set I.2a Condition 26	R21 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 1:51:50 AM



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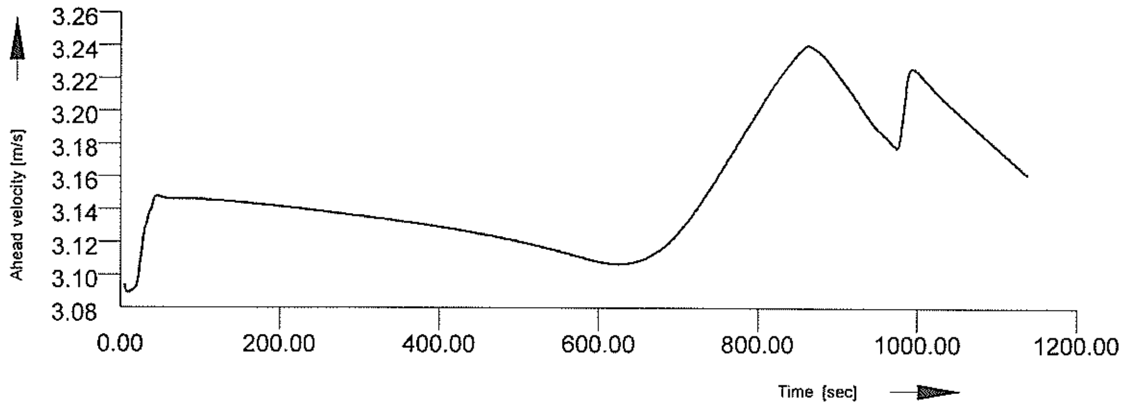
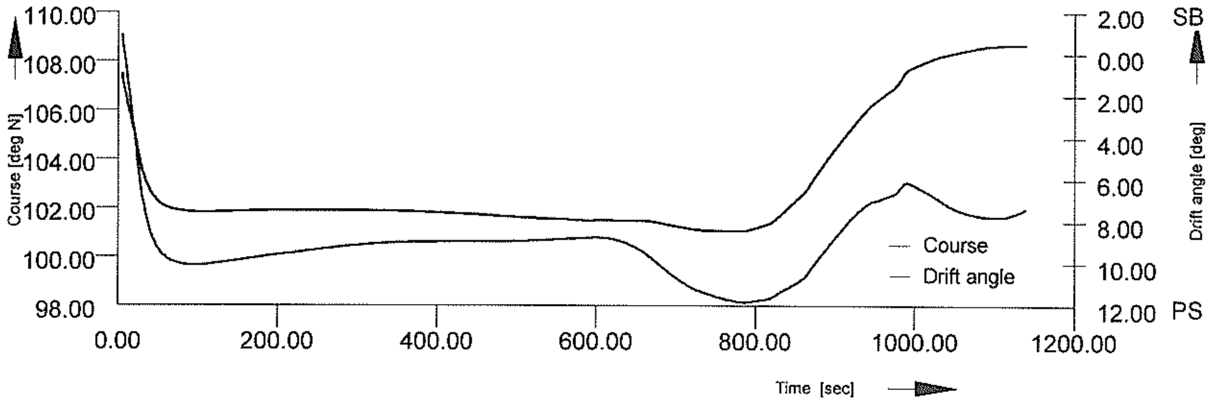
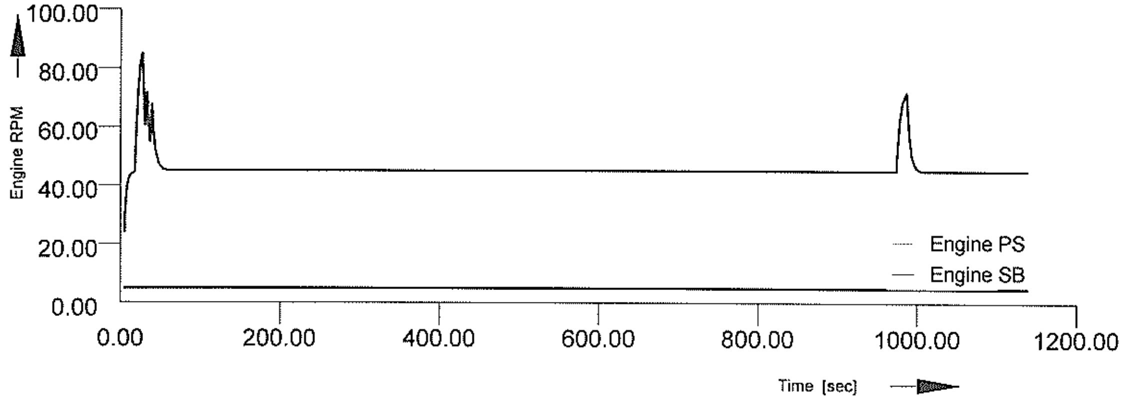
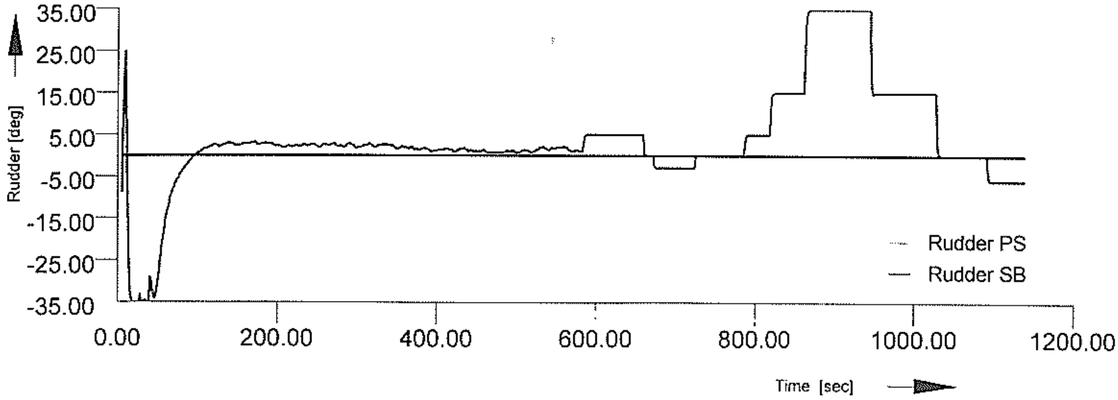
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

Alkyon 6/22/01 1:52:14 AM

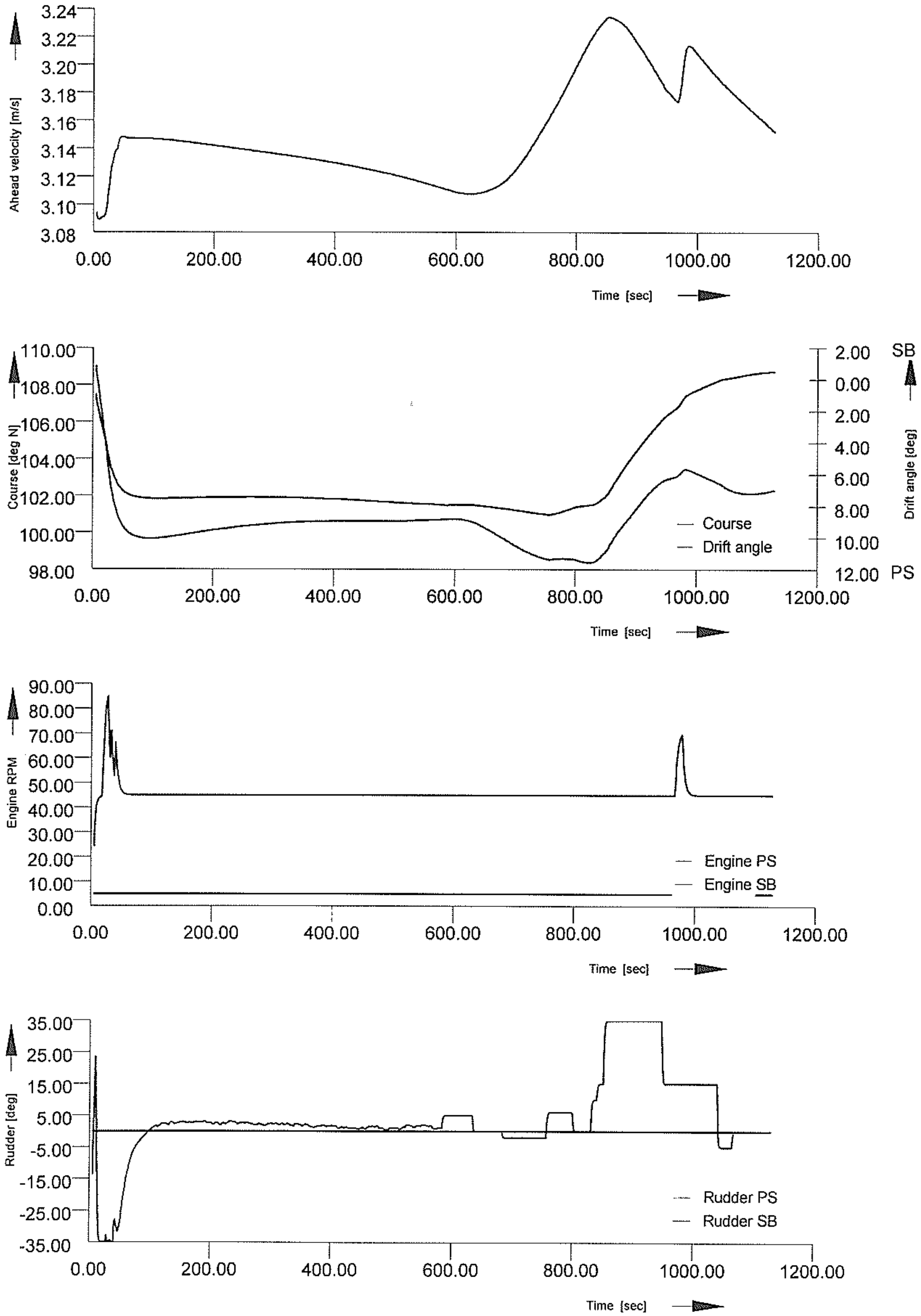




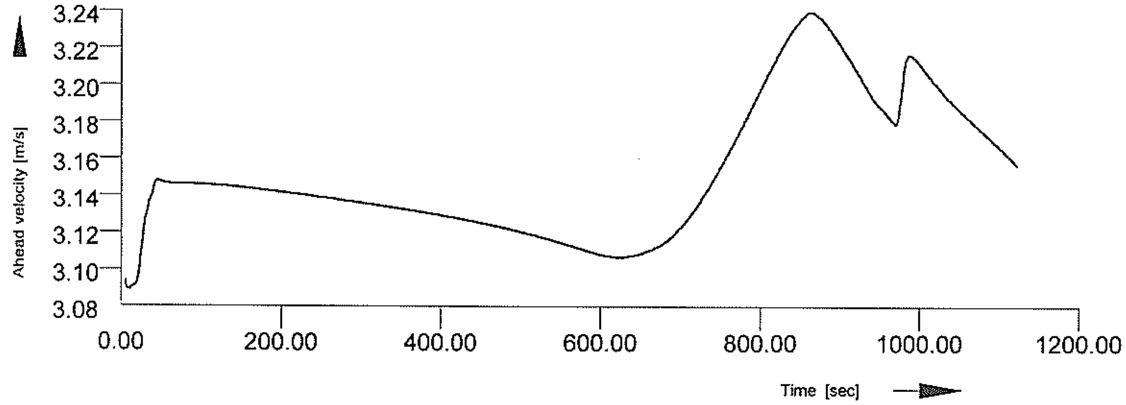


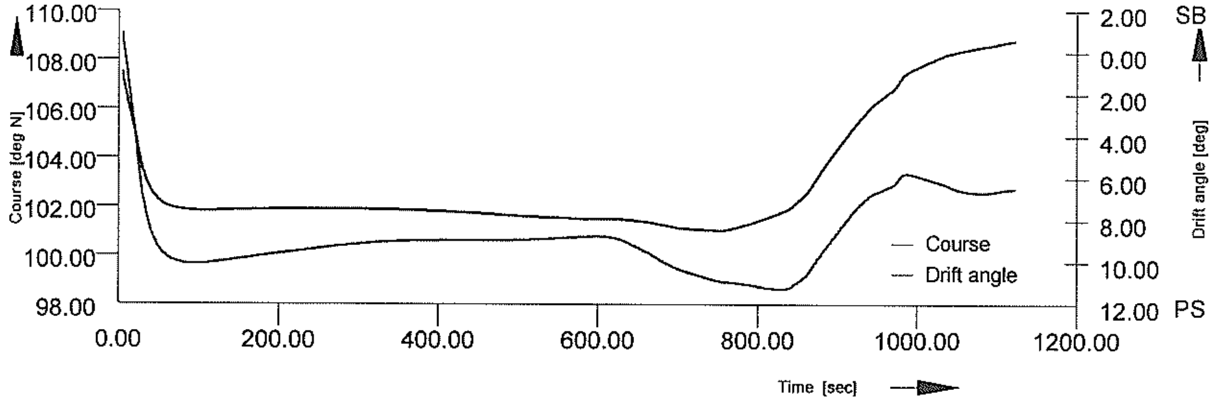


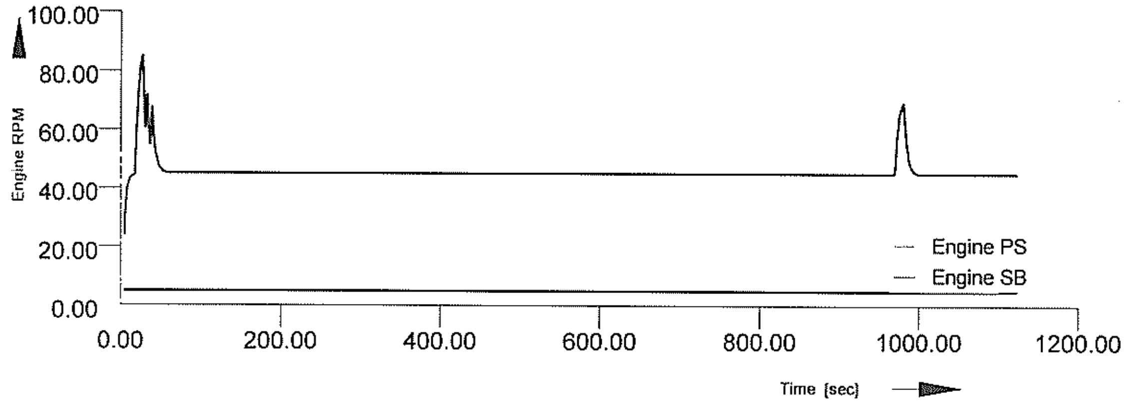
Real time Set I.2a Condition 26	R23	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

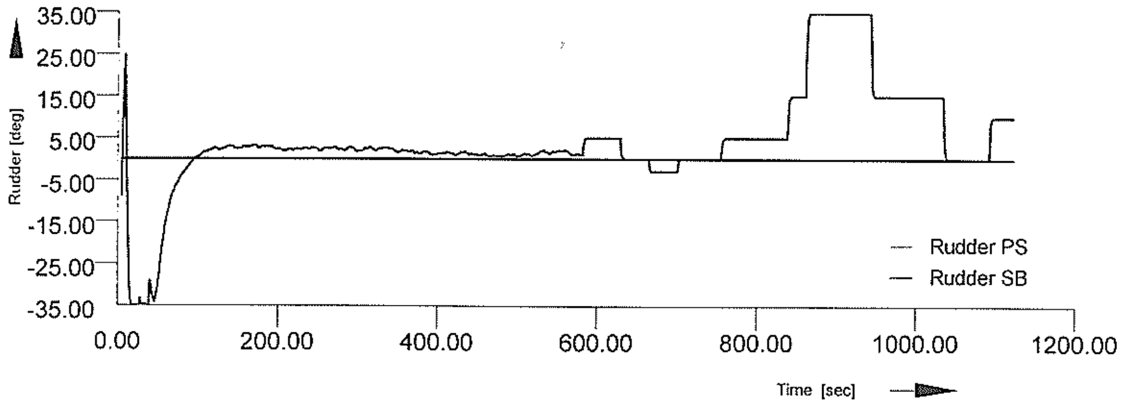


Real time Set I.2a Condition 26	R24	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	



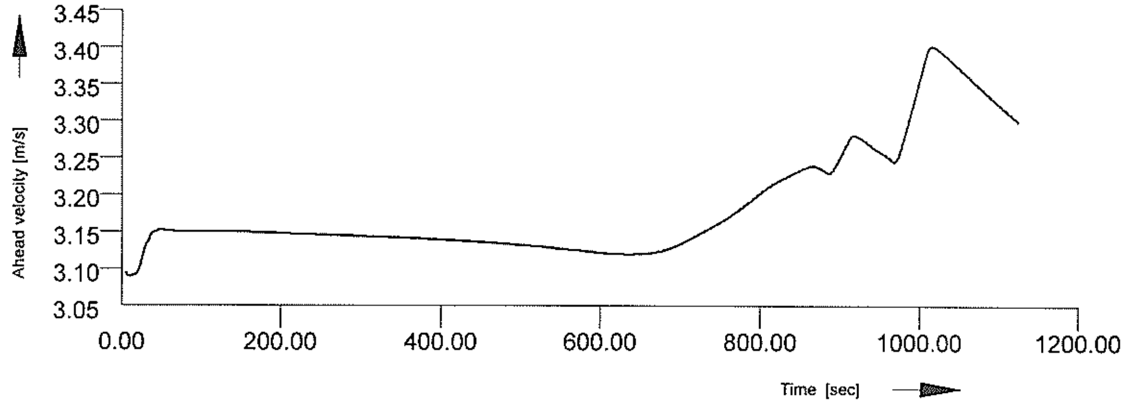


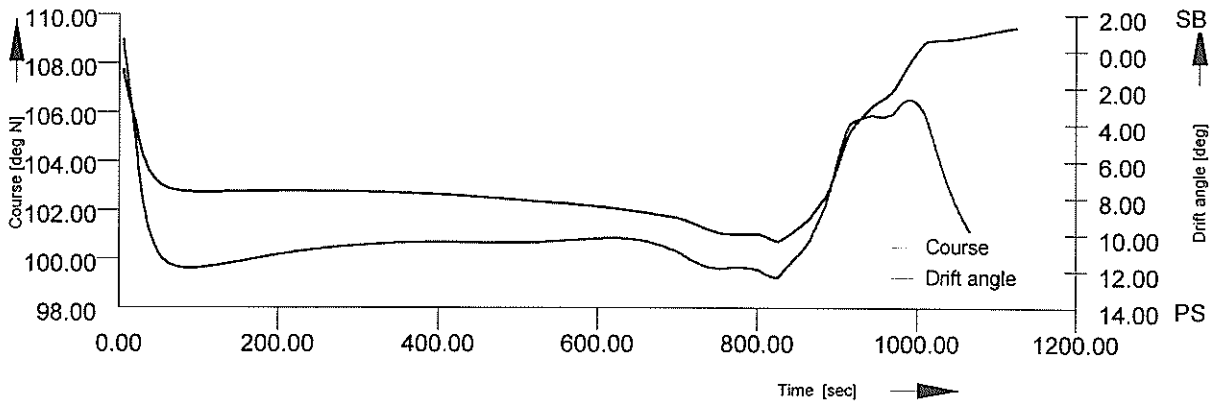


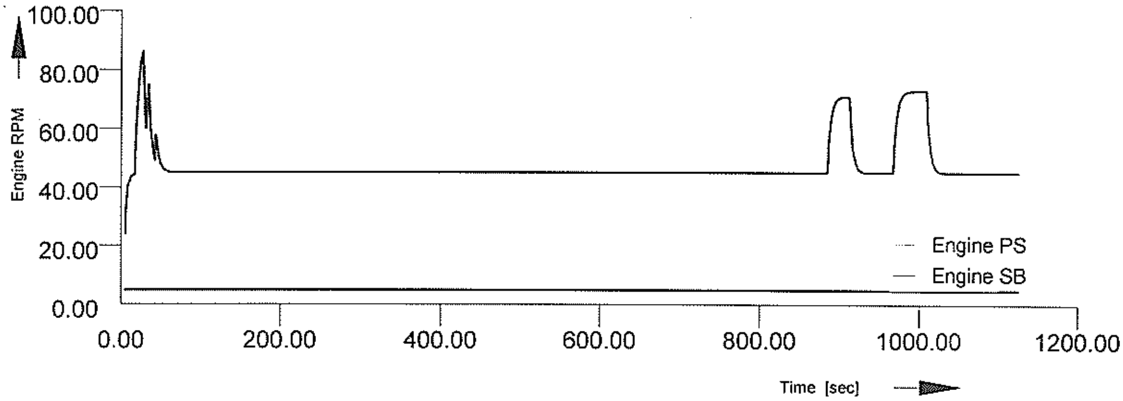


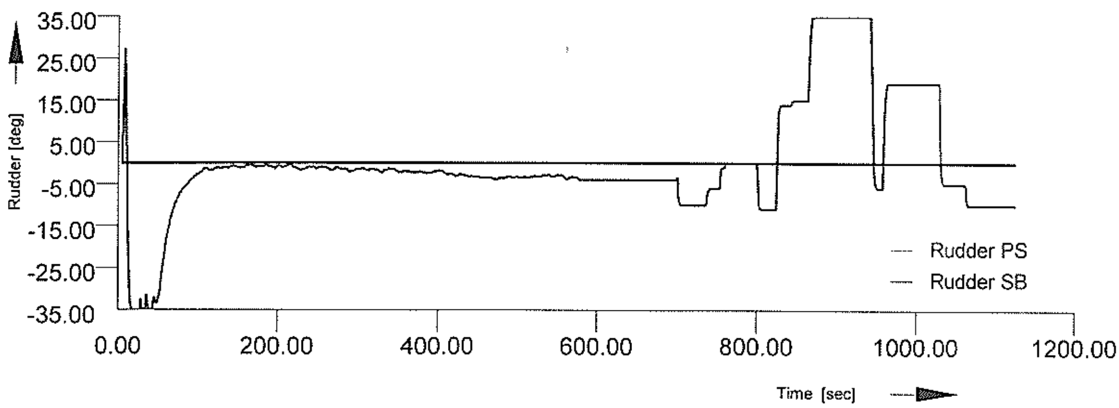
Real time Set I.2a Condition 26	R25 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Appendix XVI.3: Real time runs condition 44

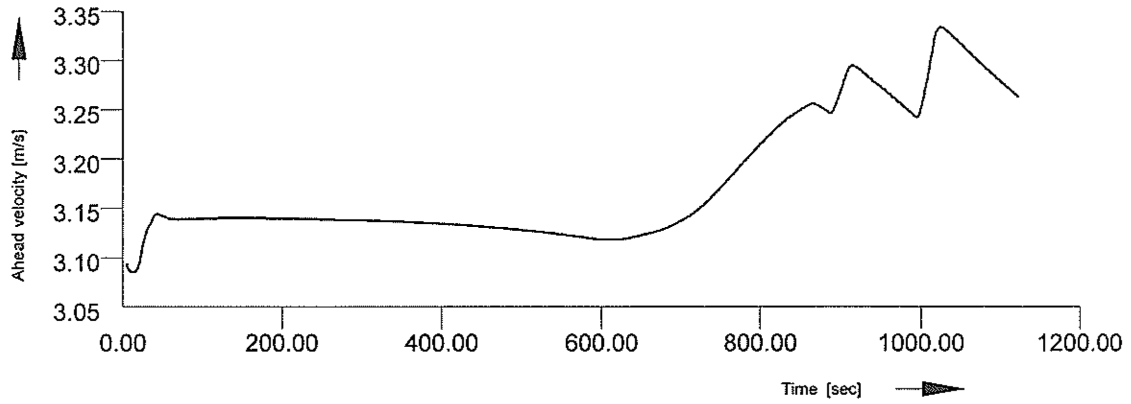


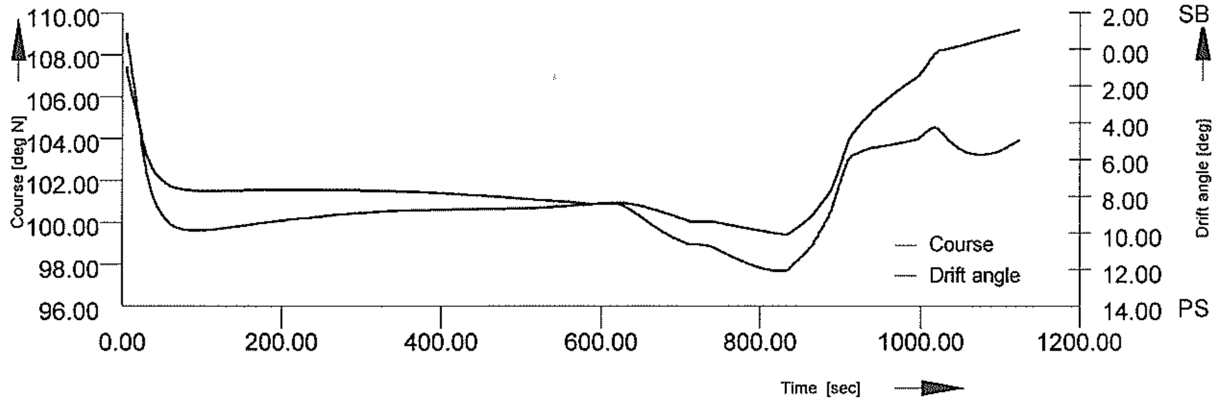


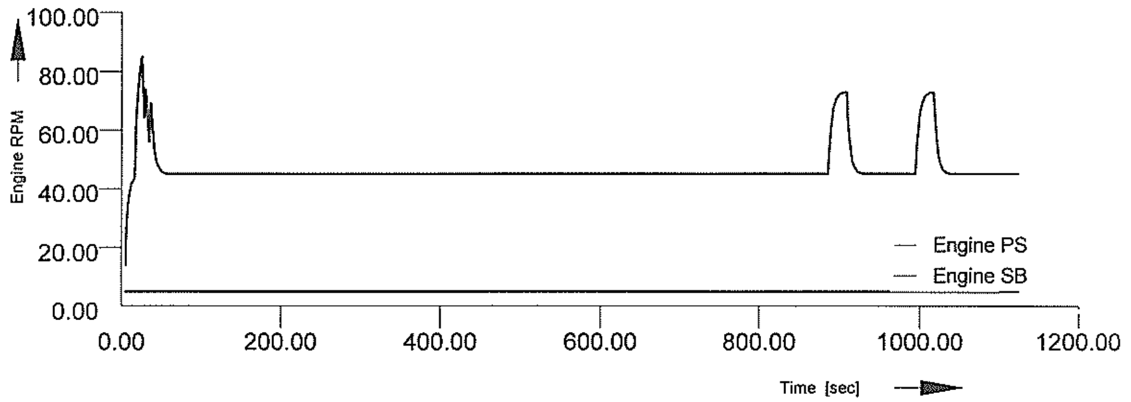


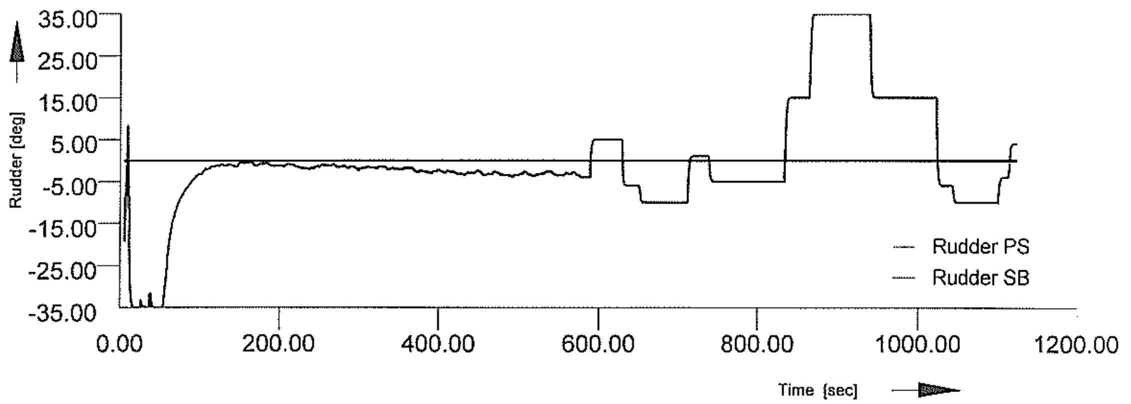


Real time Set I.2a Condition 44	R01 W. Welvaarts June 2001
AVV Transport Research Centre B010	





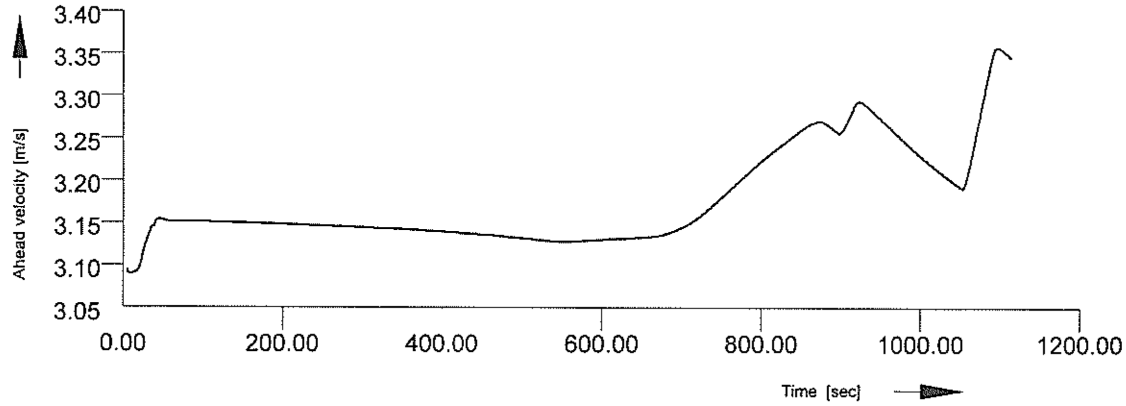


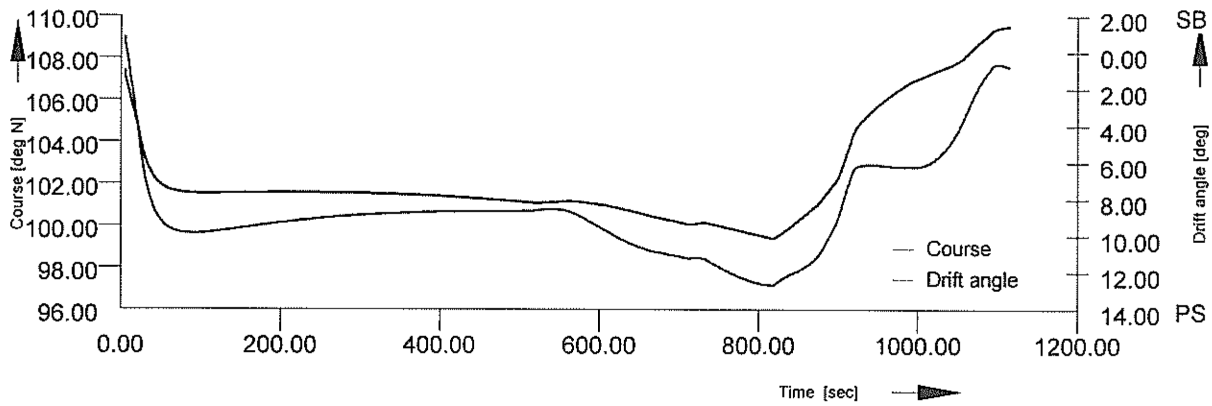


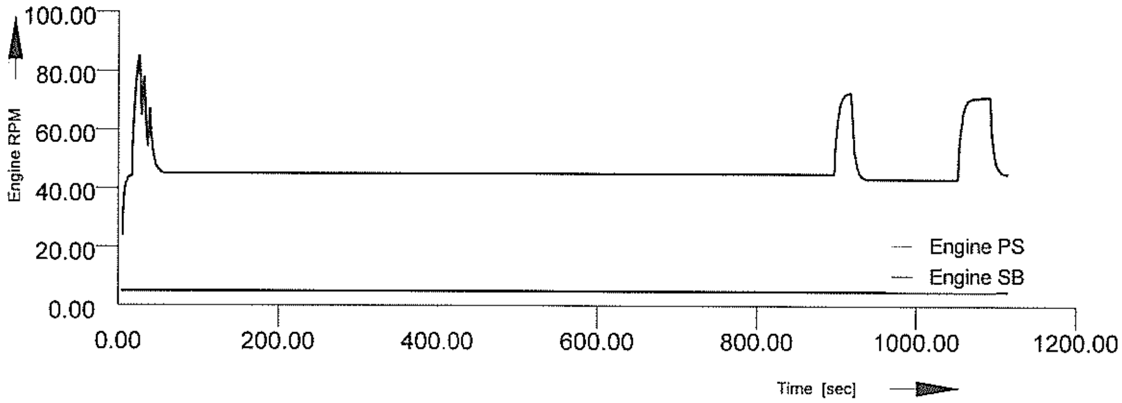
Real time
Set I.2a
Condition 44

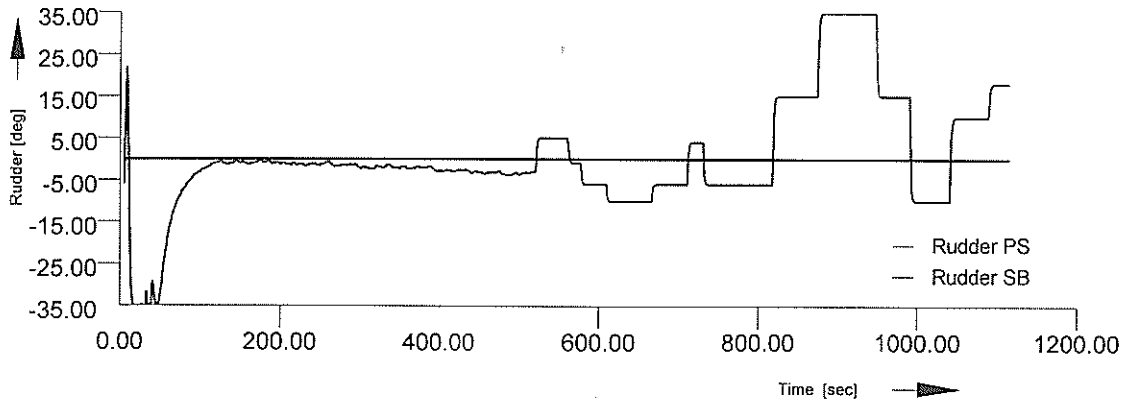
R02
W. Welvaarts
June 2001

AVV Transport Research Centre B010

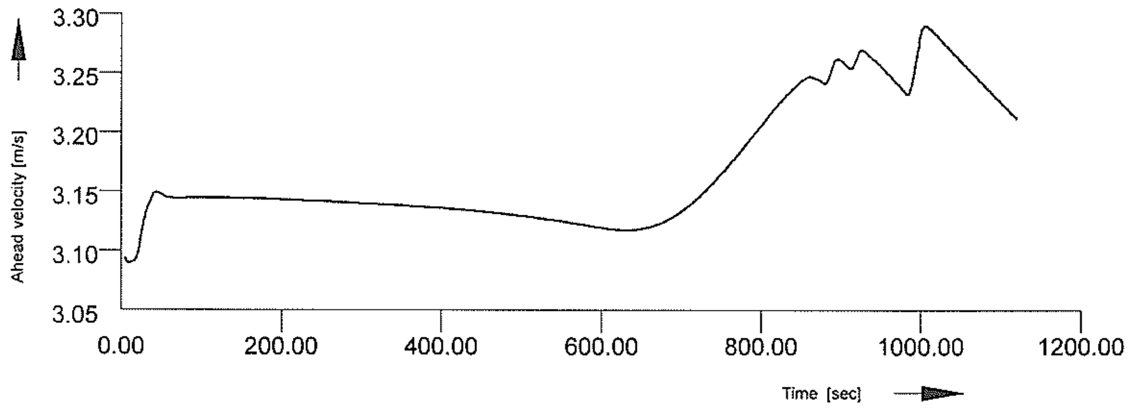


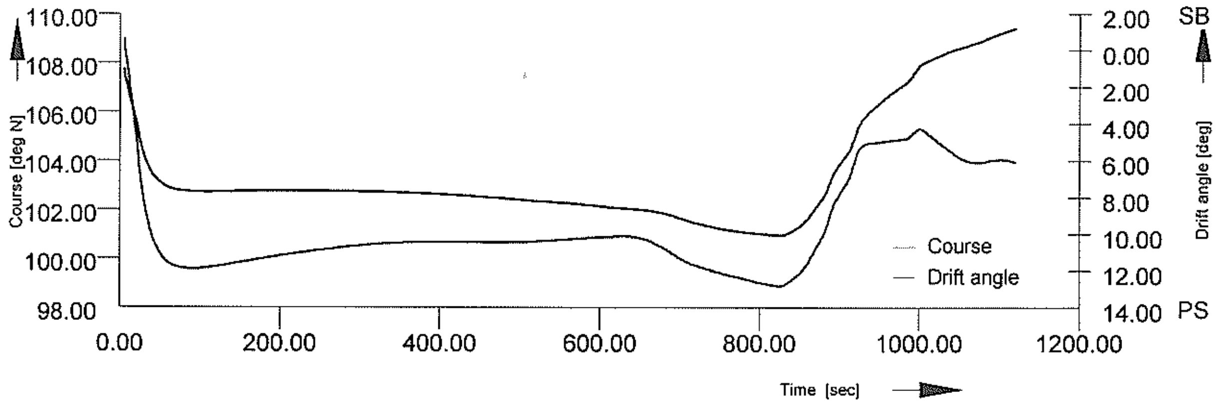


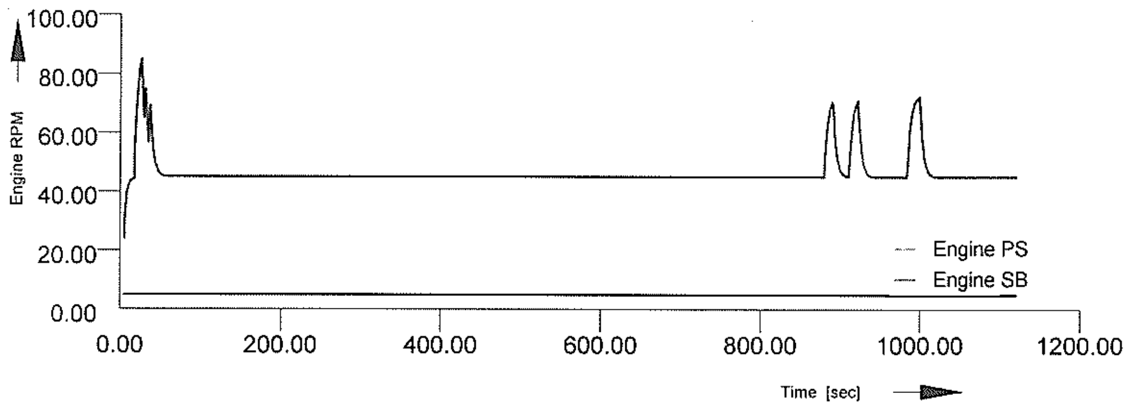


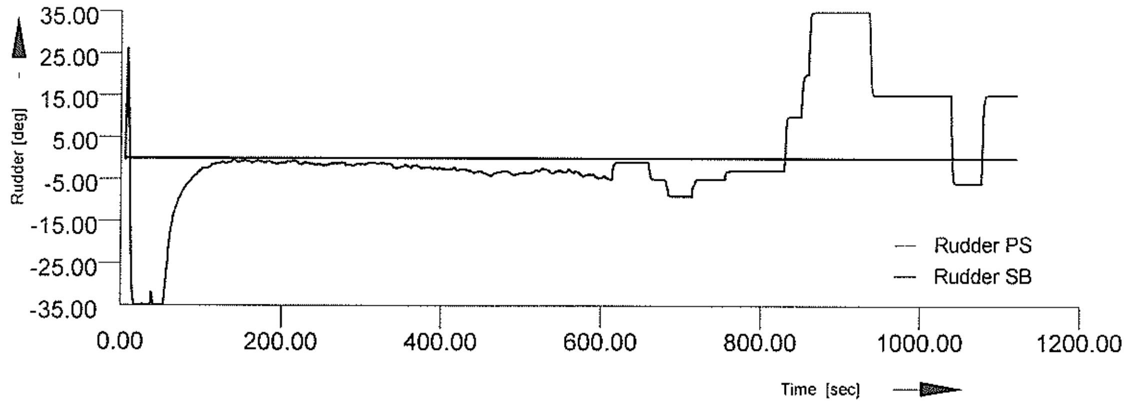


Real time Set I.2a Condition 44	R03 W. Welvaarts June 2001
AVV Transport Research Centre B010	





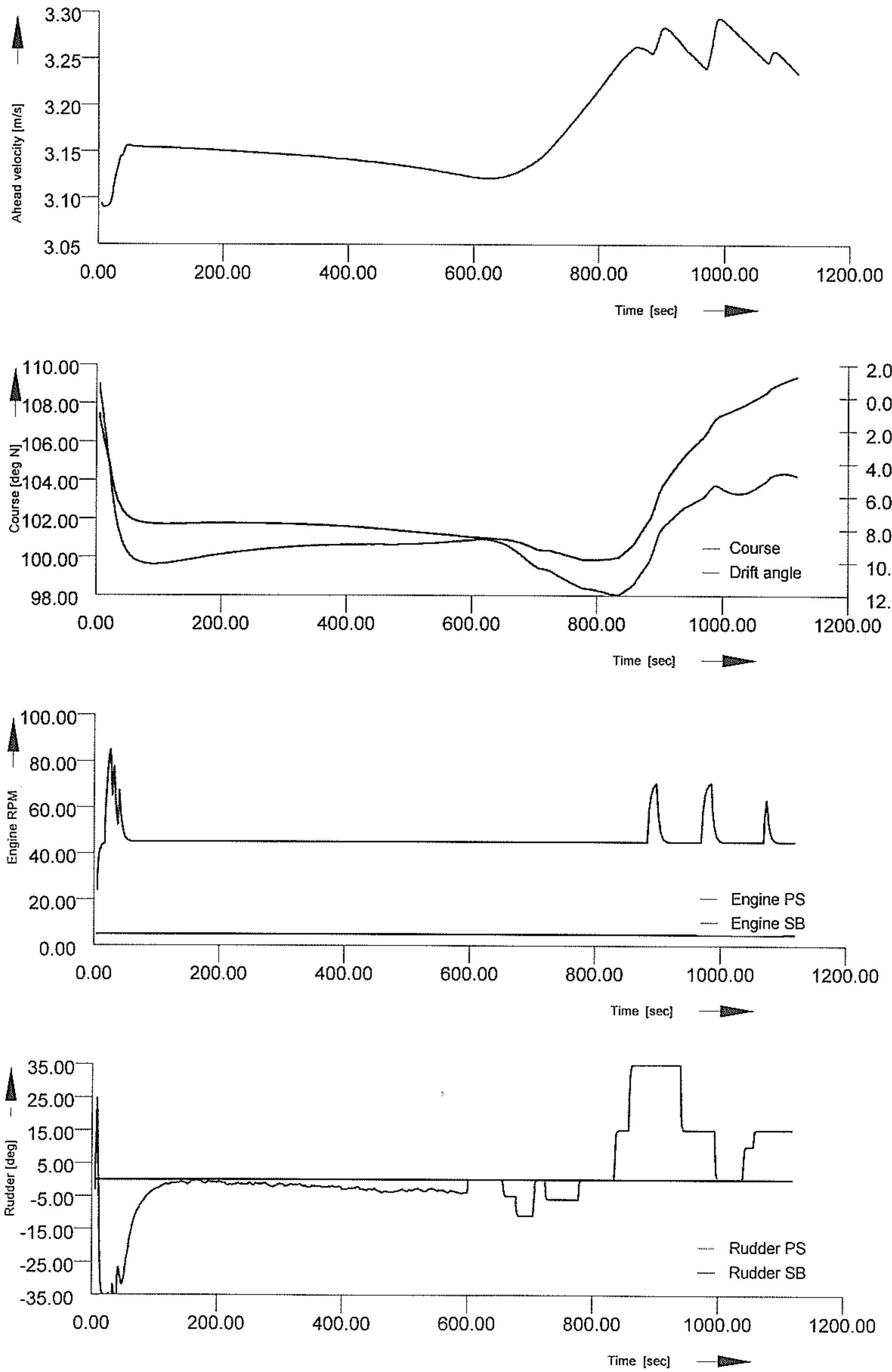




Real time
Set I.2a
Condition 44

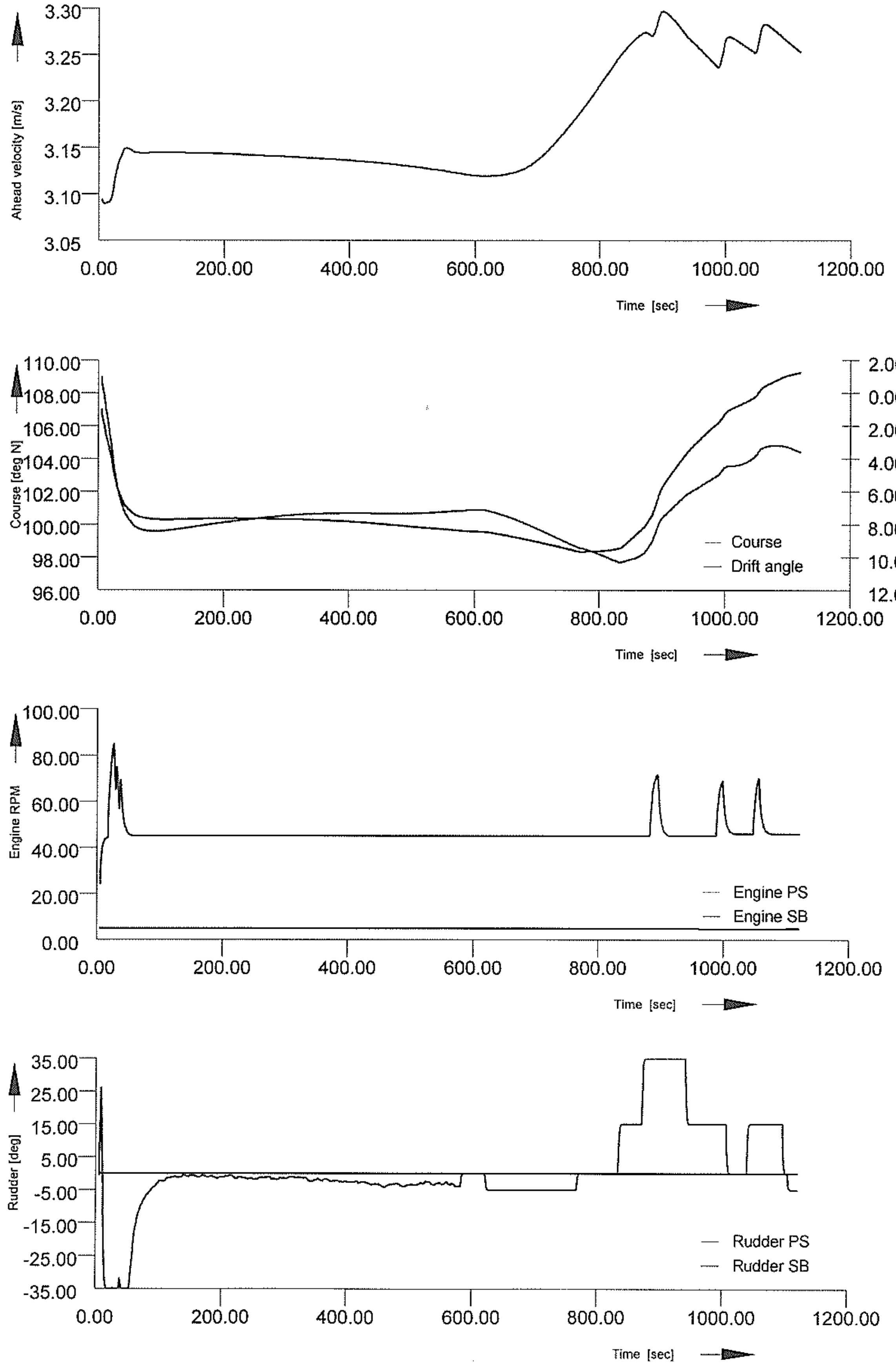
R08
W. Welvaarts
June 2001

AVV Transport Research Centre B010

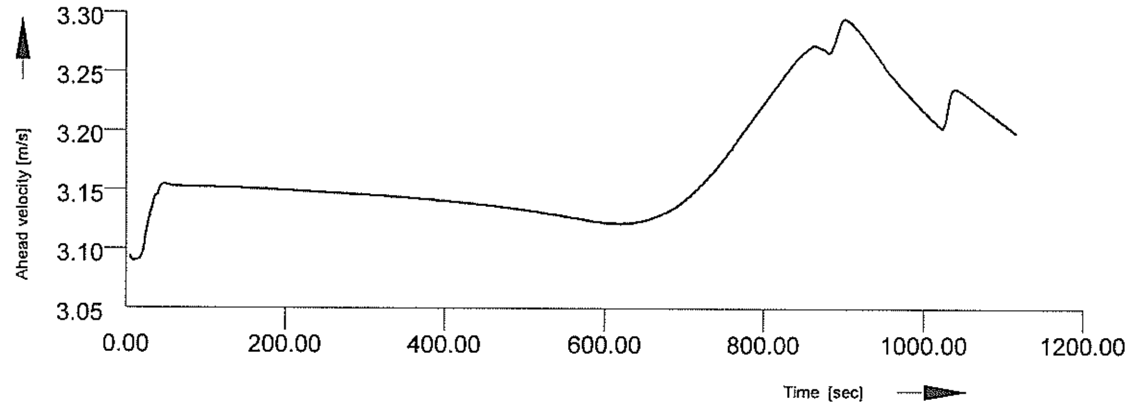


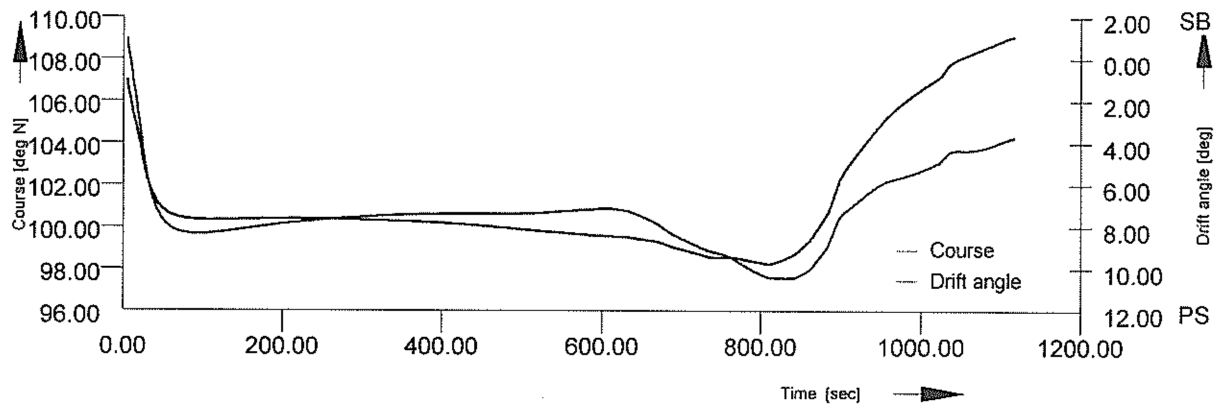
Real time Set I.2a Condition 44	R10	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

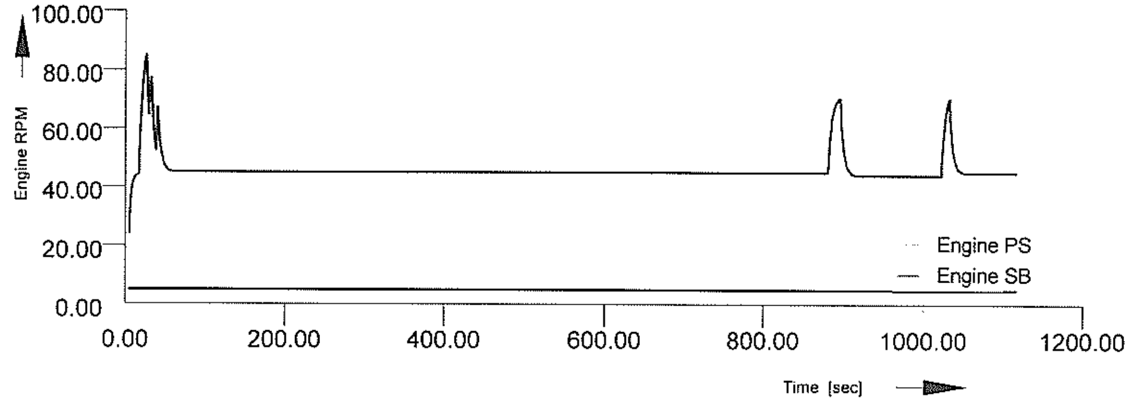
Alkyon 6/22/01 2:15:16 AM

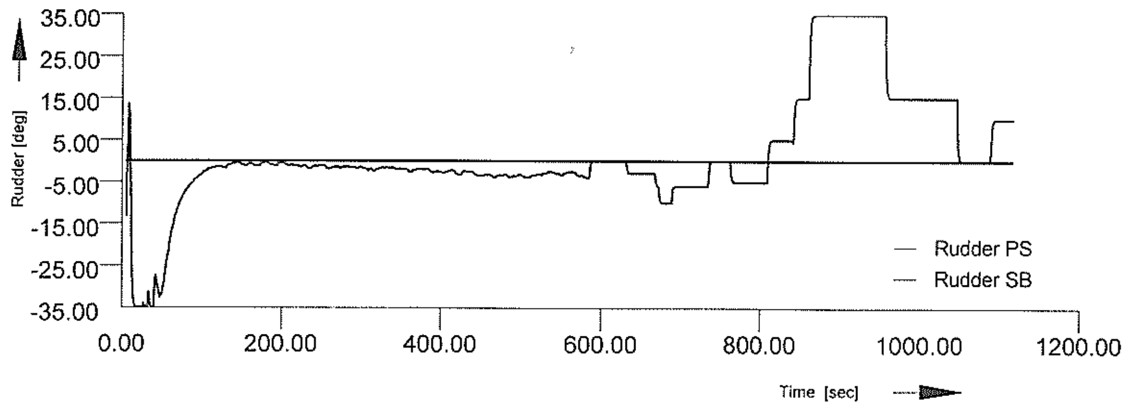


Real time Set I.2a Condition 44	R11 W. Welvaarts June 2001
AVV Transport Research Centre B010	

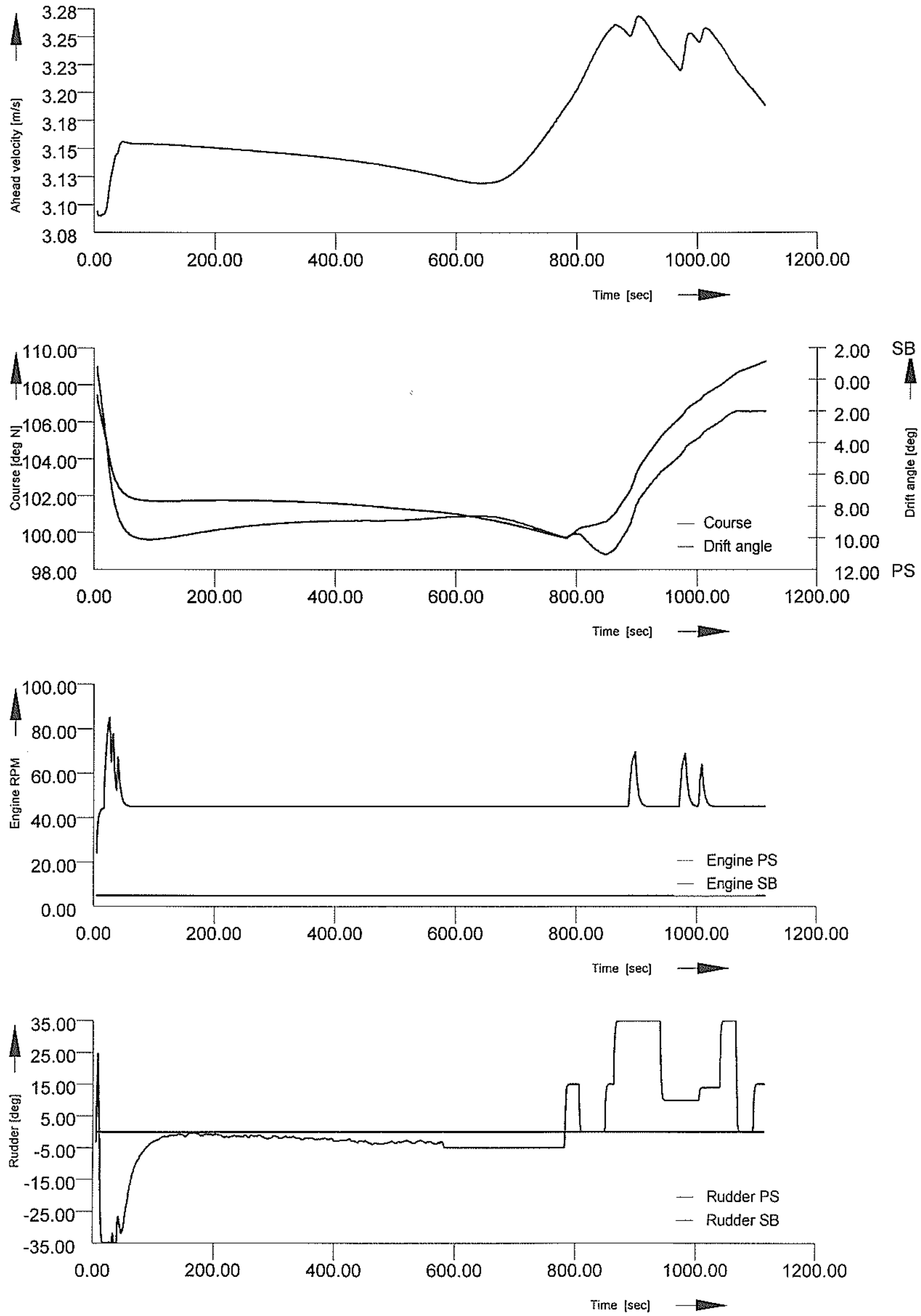




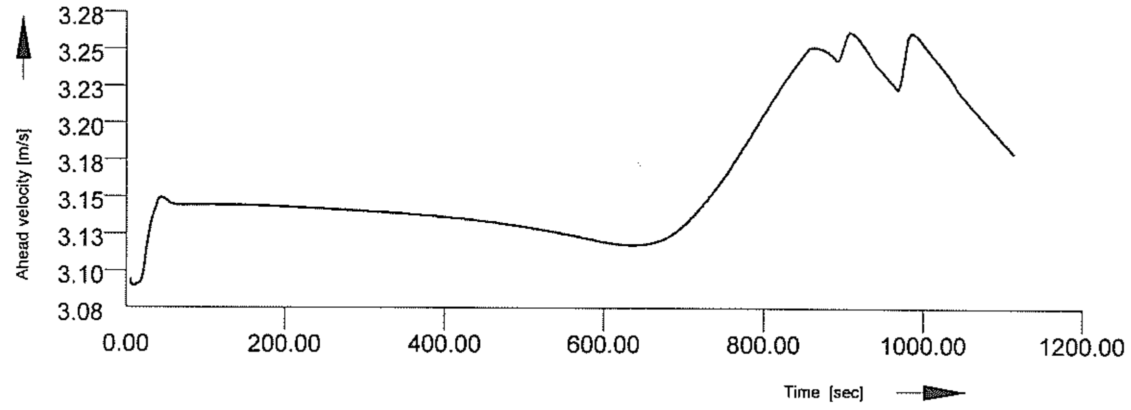


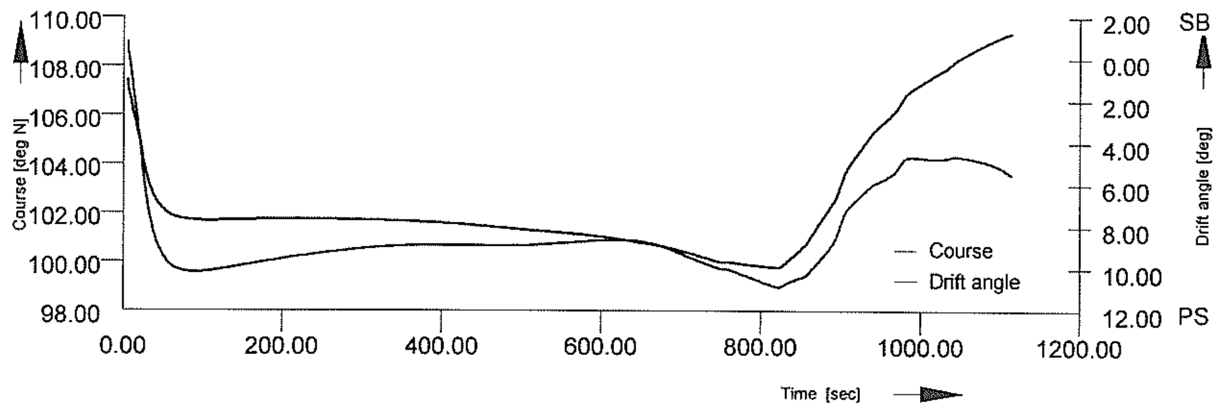


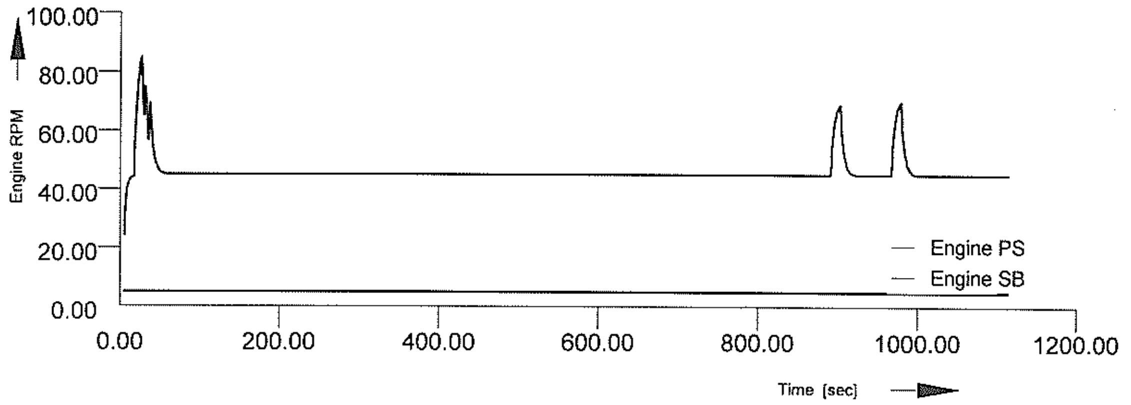
Real time Set I.2a Condition 44	R12	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

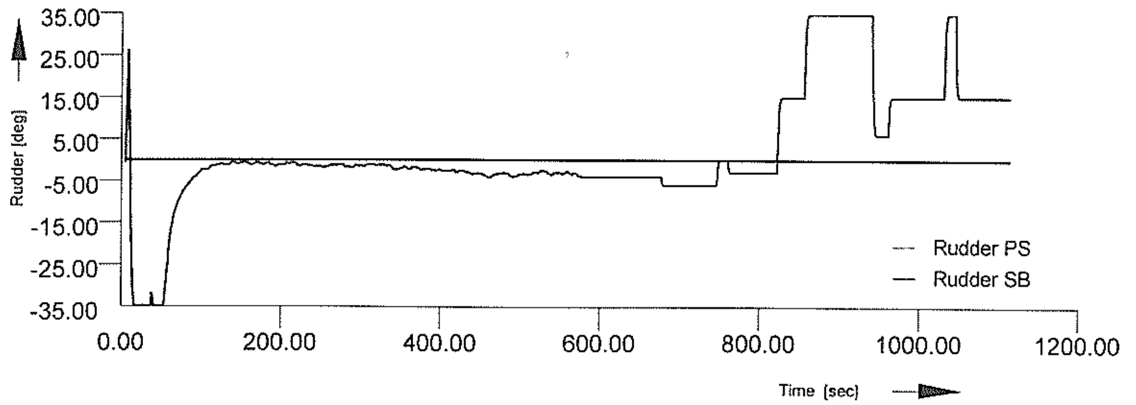


Real time Set I.2a Condition 44		R13	
		W. Welvaarts	
		June 2001	
AVV Transport Research Centre	B010		

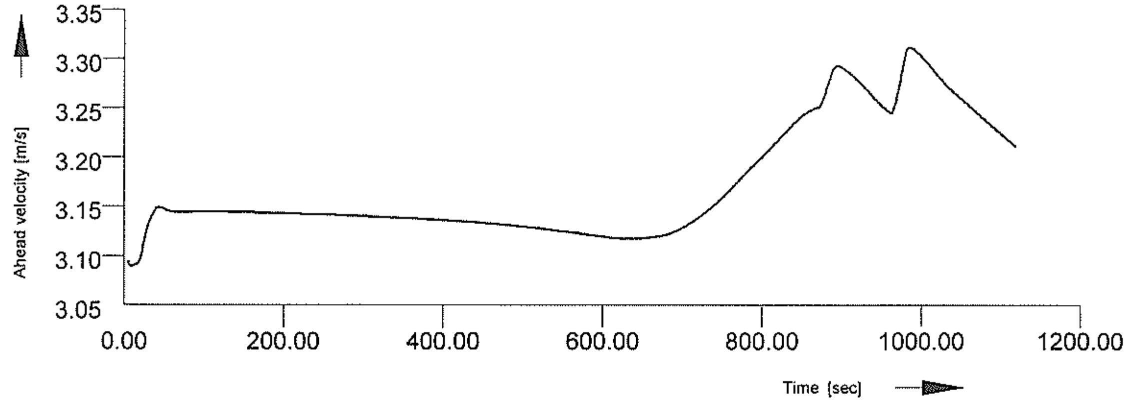


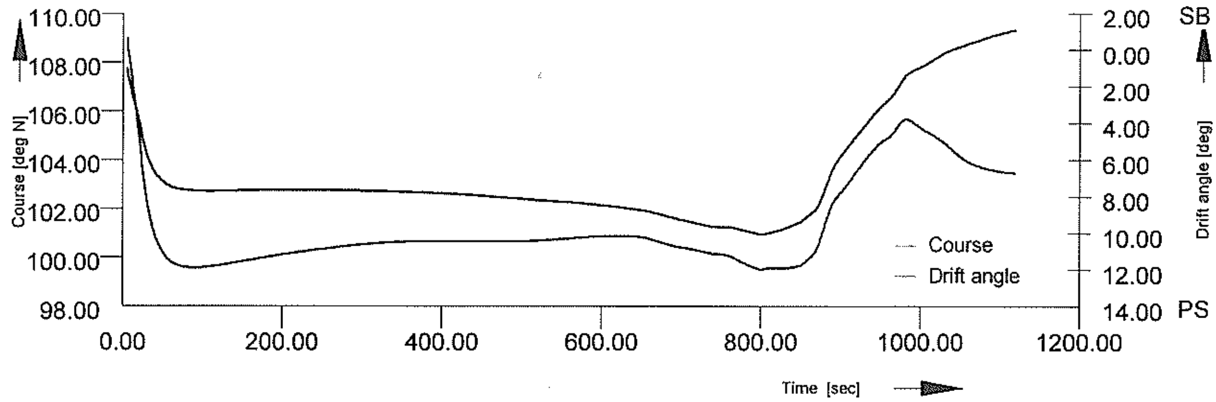


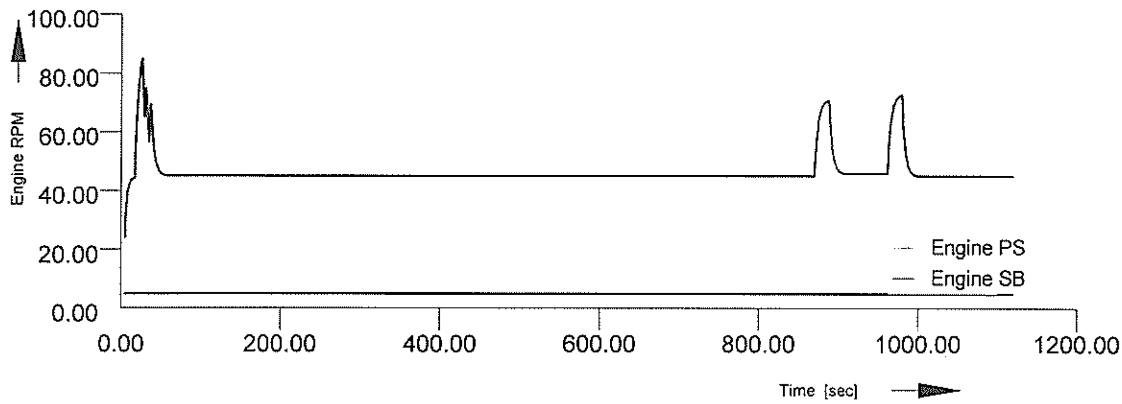


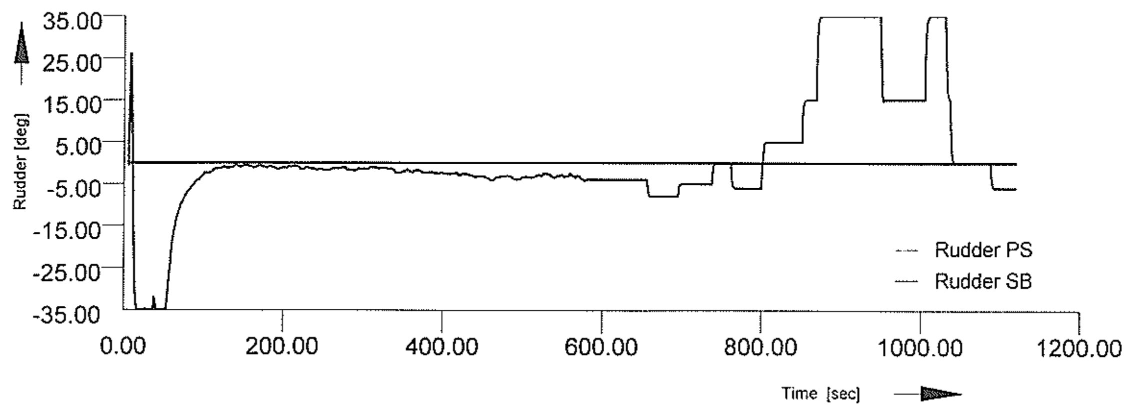


Real time Set I.2a Condition 44	R14 W. Welvaarts June 2001
AVV Transport Research Centre B010	



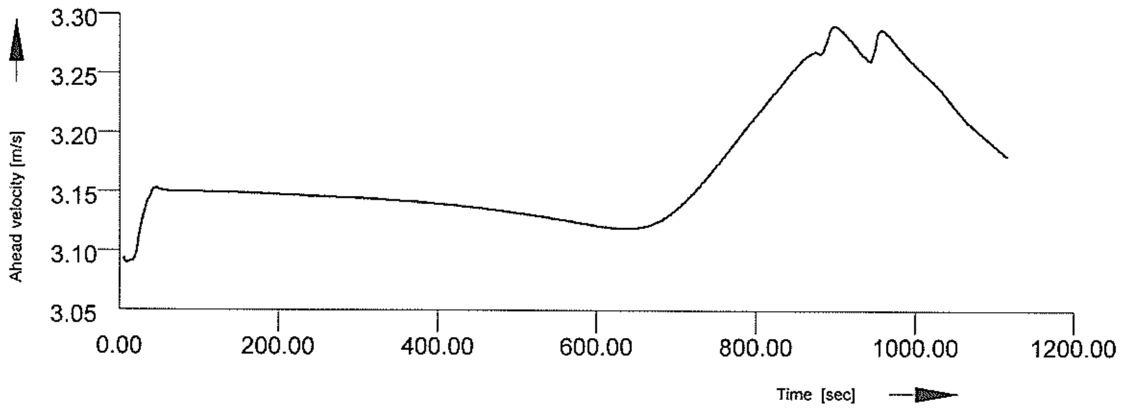


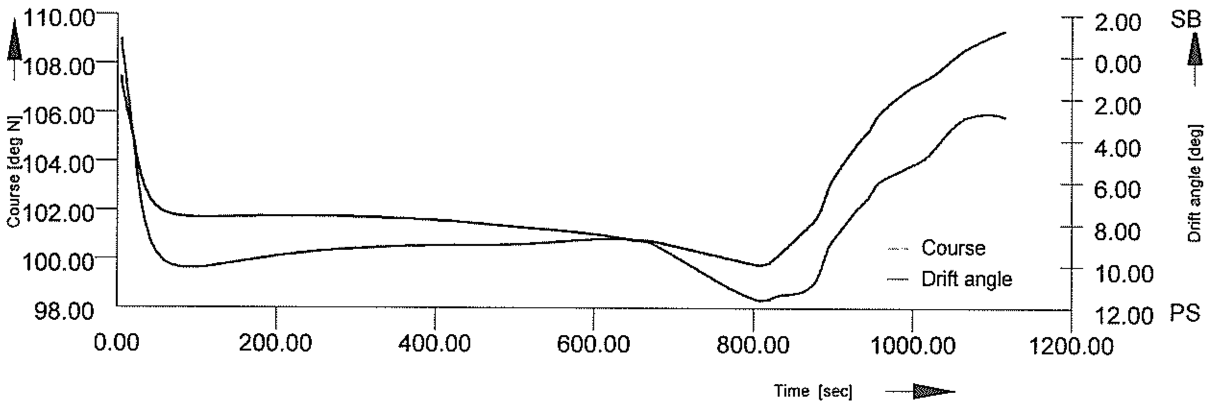


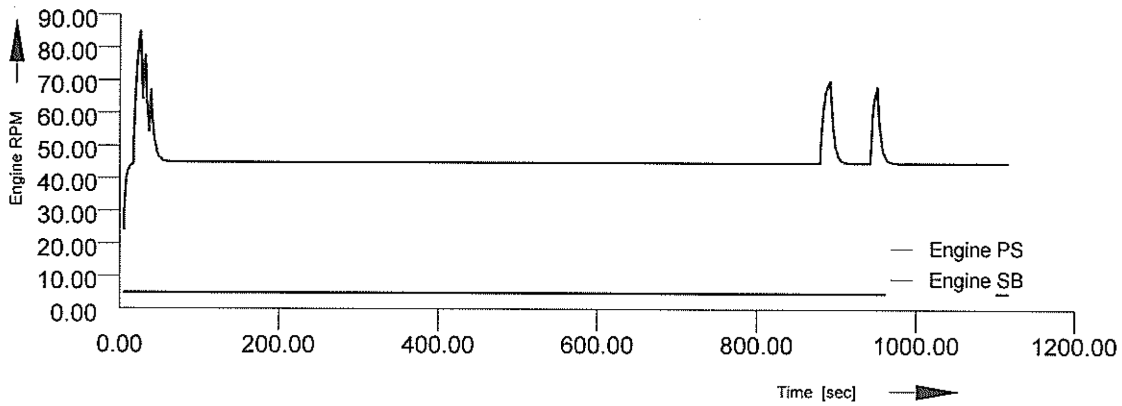


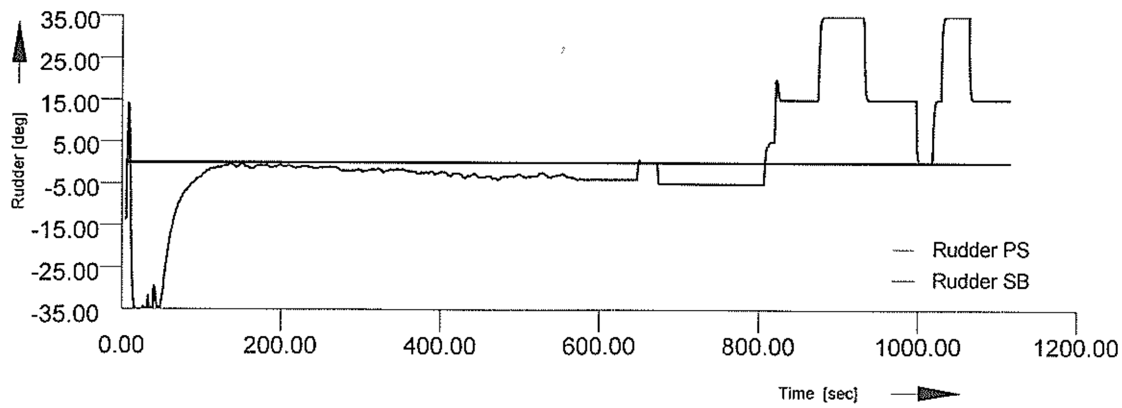
Real time Set I.2a Condition 44	R16 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 2:29:51 AM



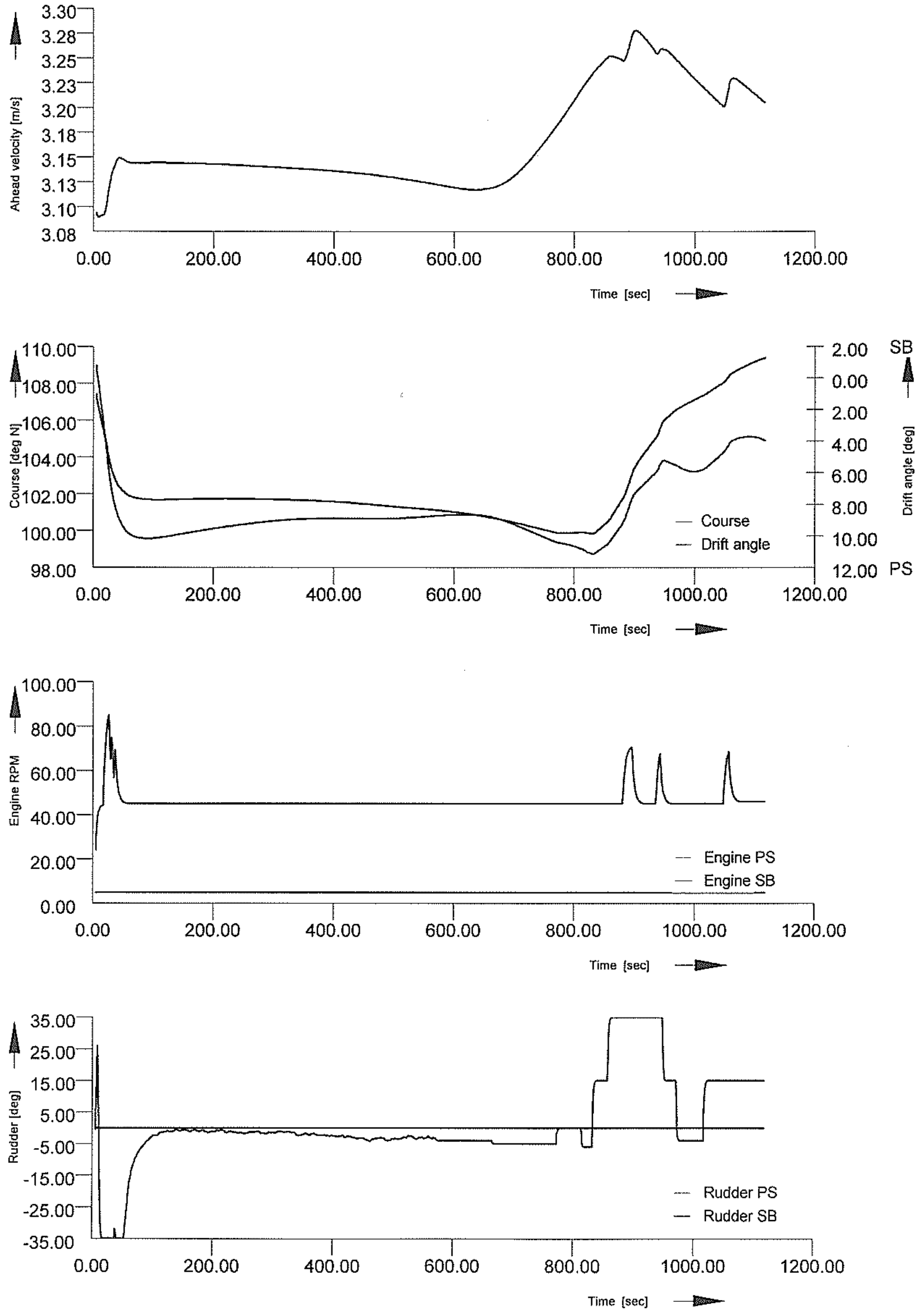




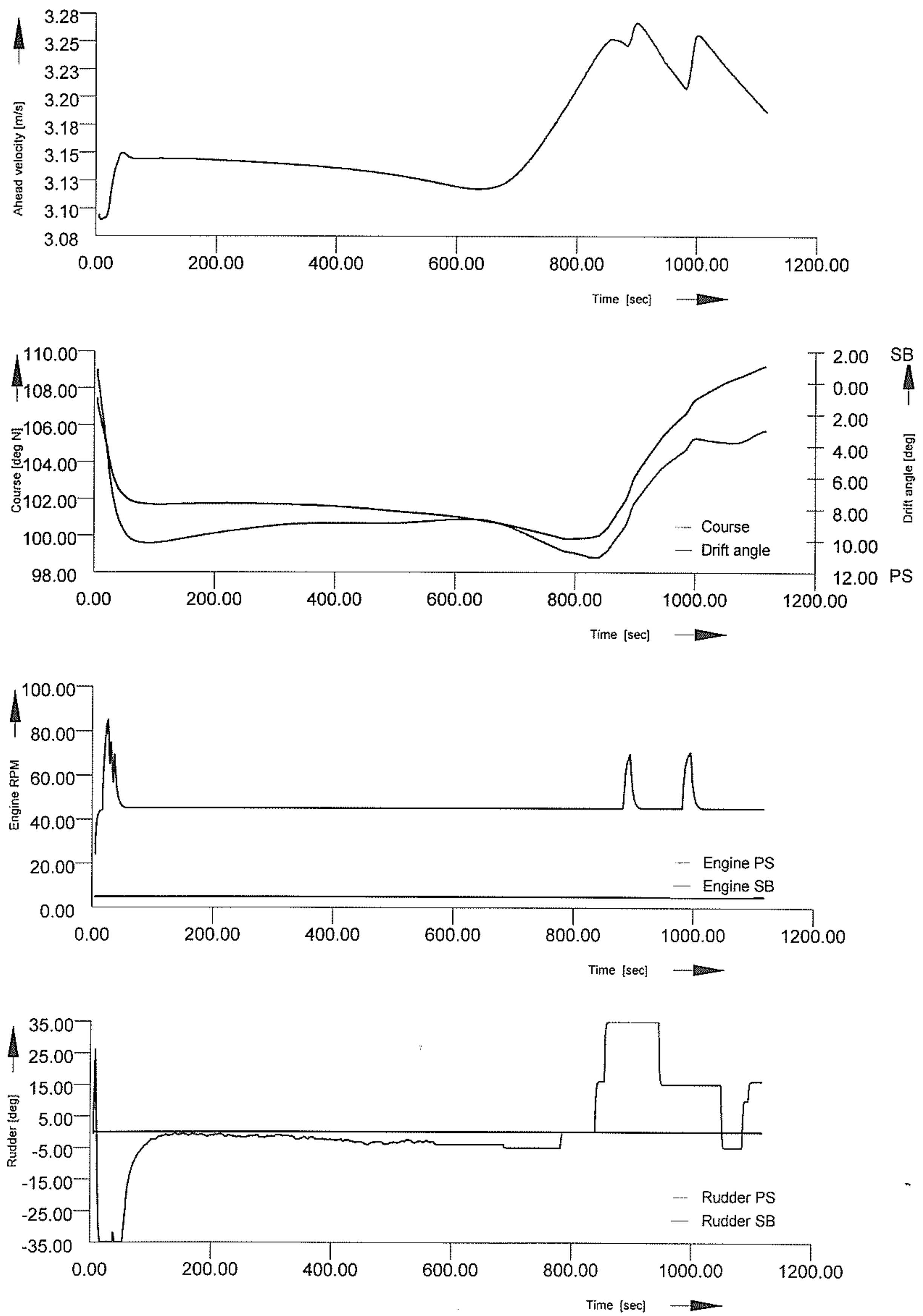


Real time Set I.2a Condition 44	R17	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

Alkyon 6/22/01 2:30:21 AM

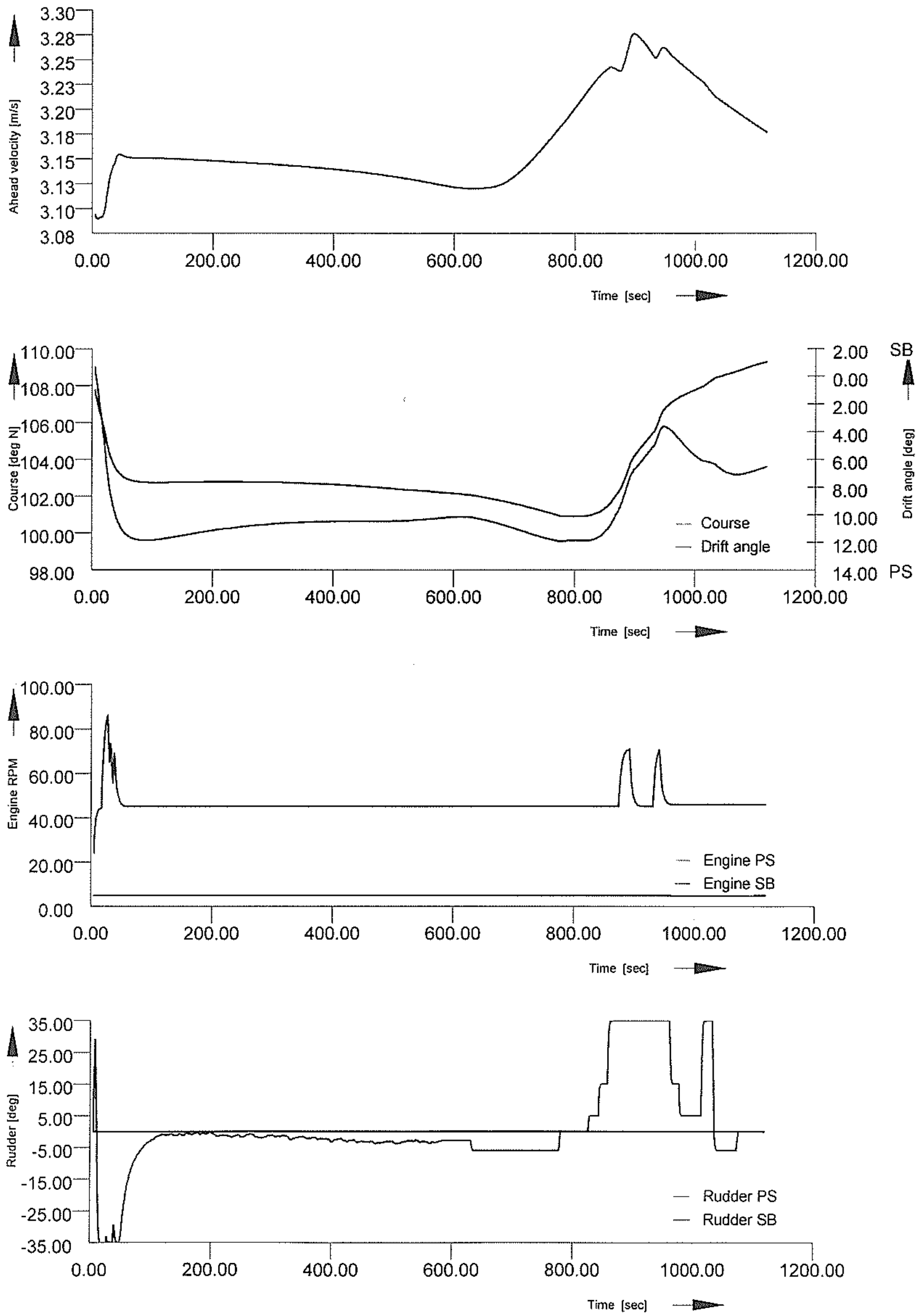


Real time Set I.2a Condition 44	R18 W. Welvaarts June 2001
AVV Transport Research Centre B010	

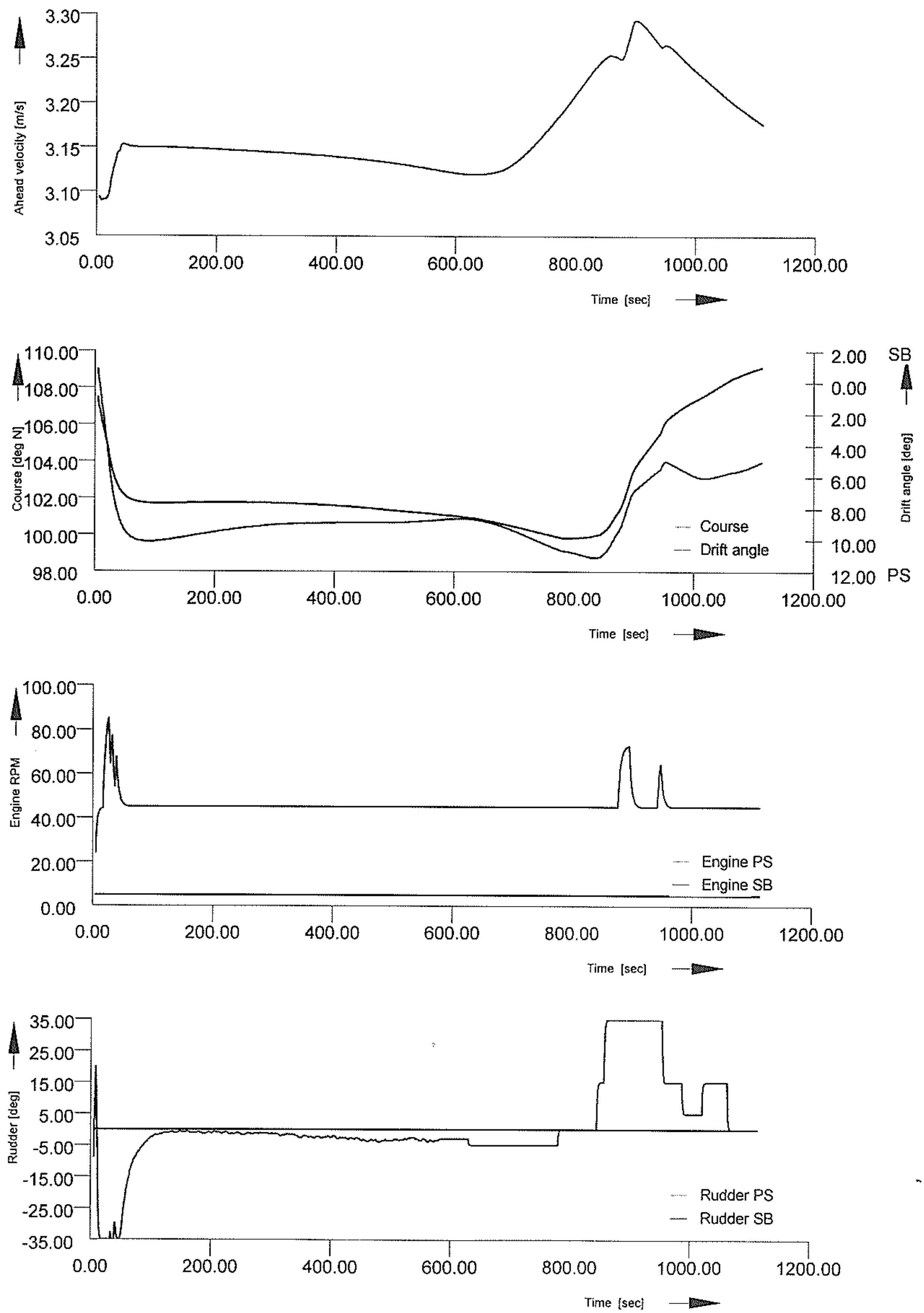


Real time Set I.2a Condition 44	R19 W. Welvaarts June 2001
AVV Transport Research Centre B010	

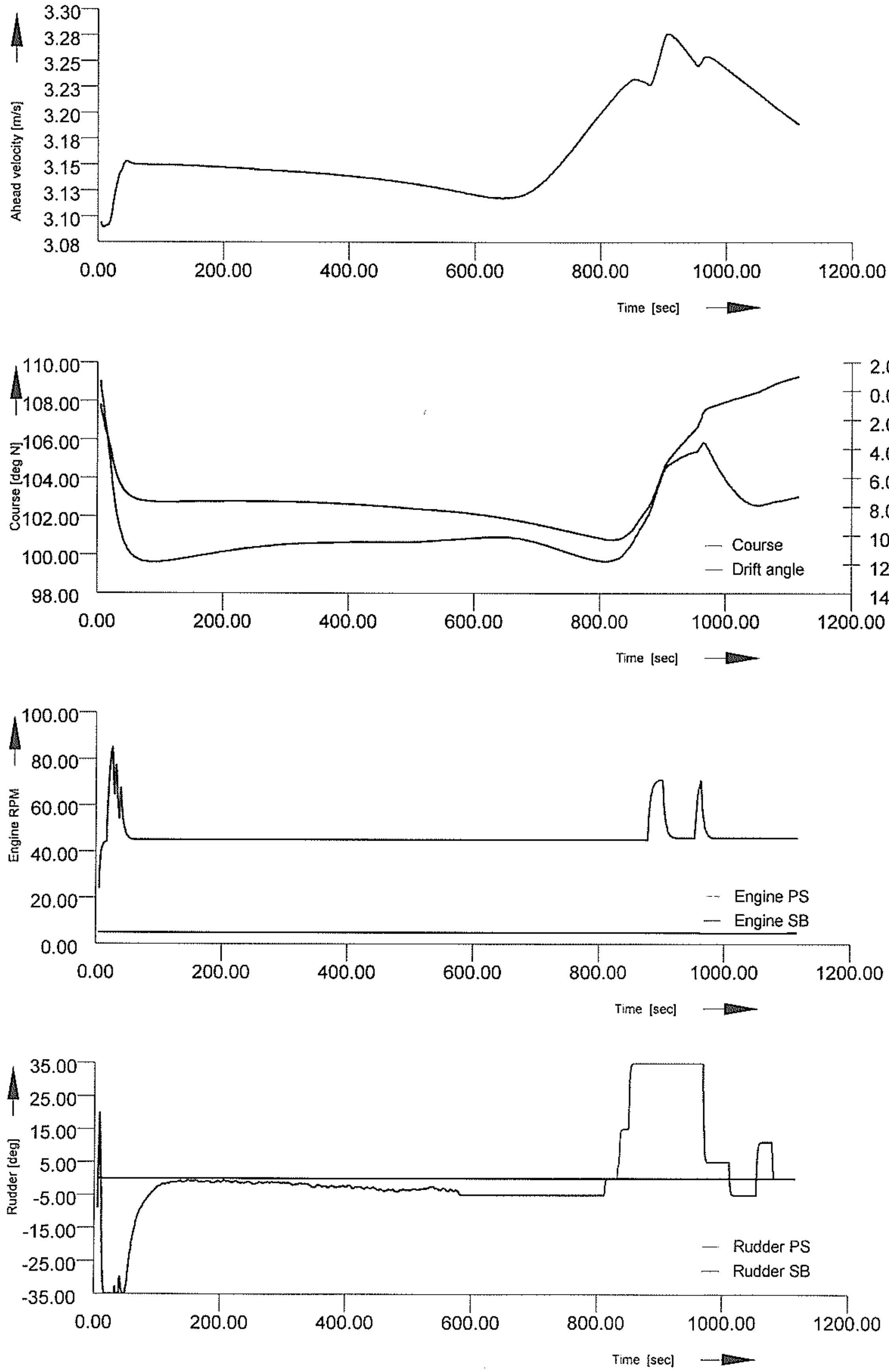
Alkyon 6/22/01 2 31:20 AM



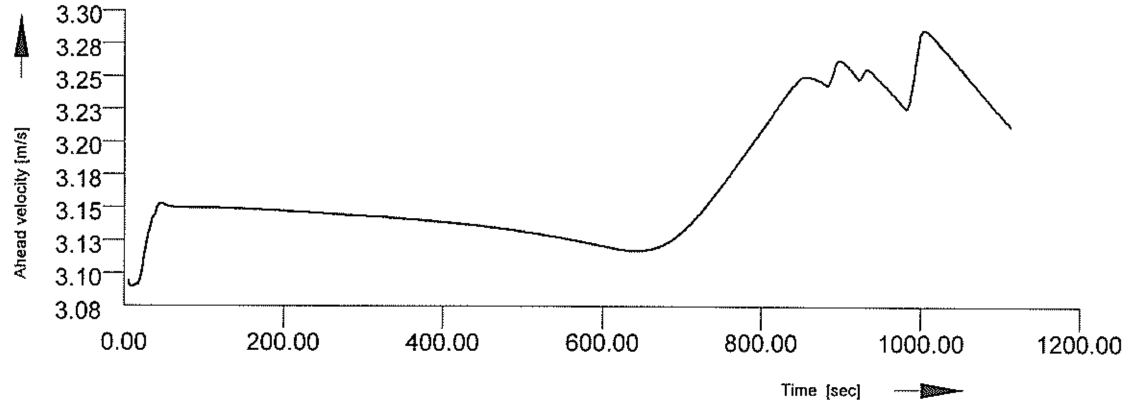
Real time Set I.2a Condition 44	R20	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

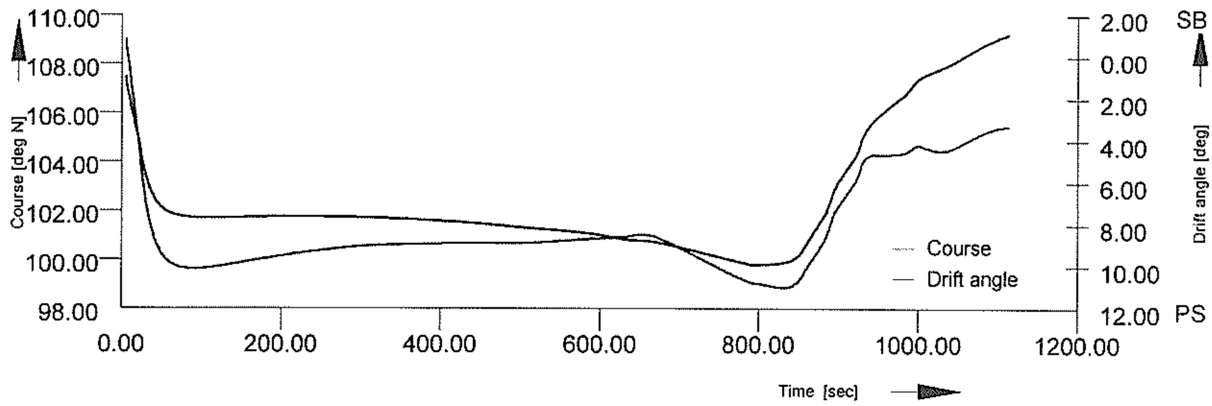


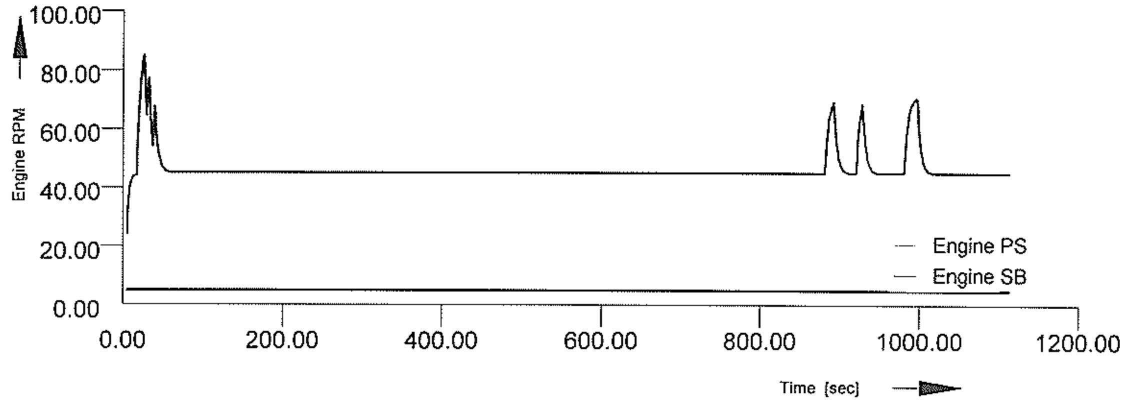
Real time Set I.2a Condition 44	R21	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

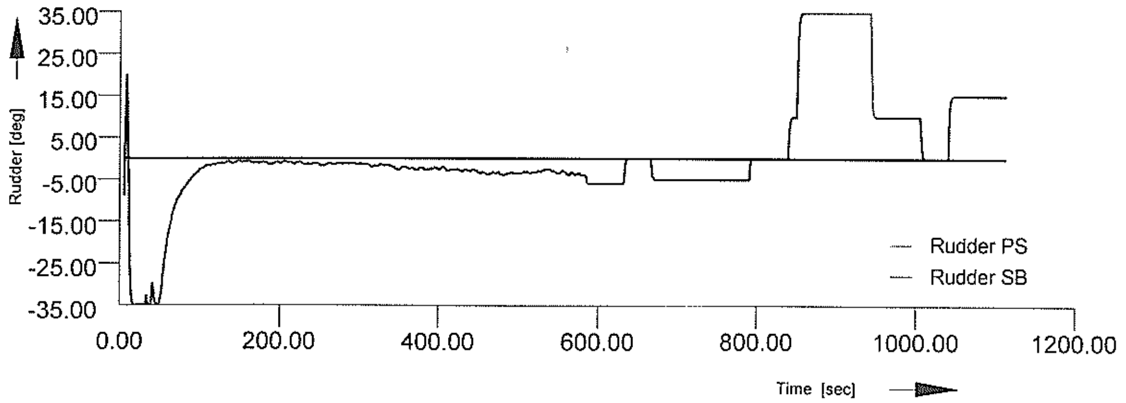


Real time Set I.2a Condition 44	R22	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	



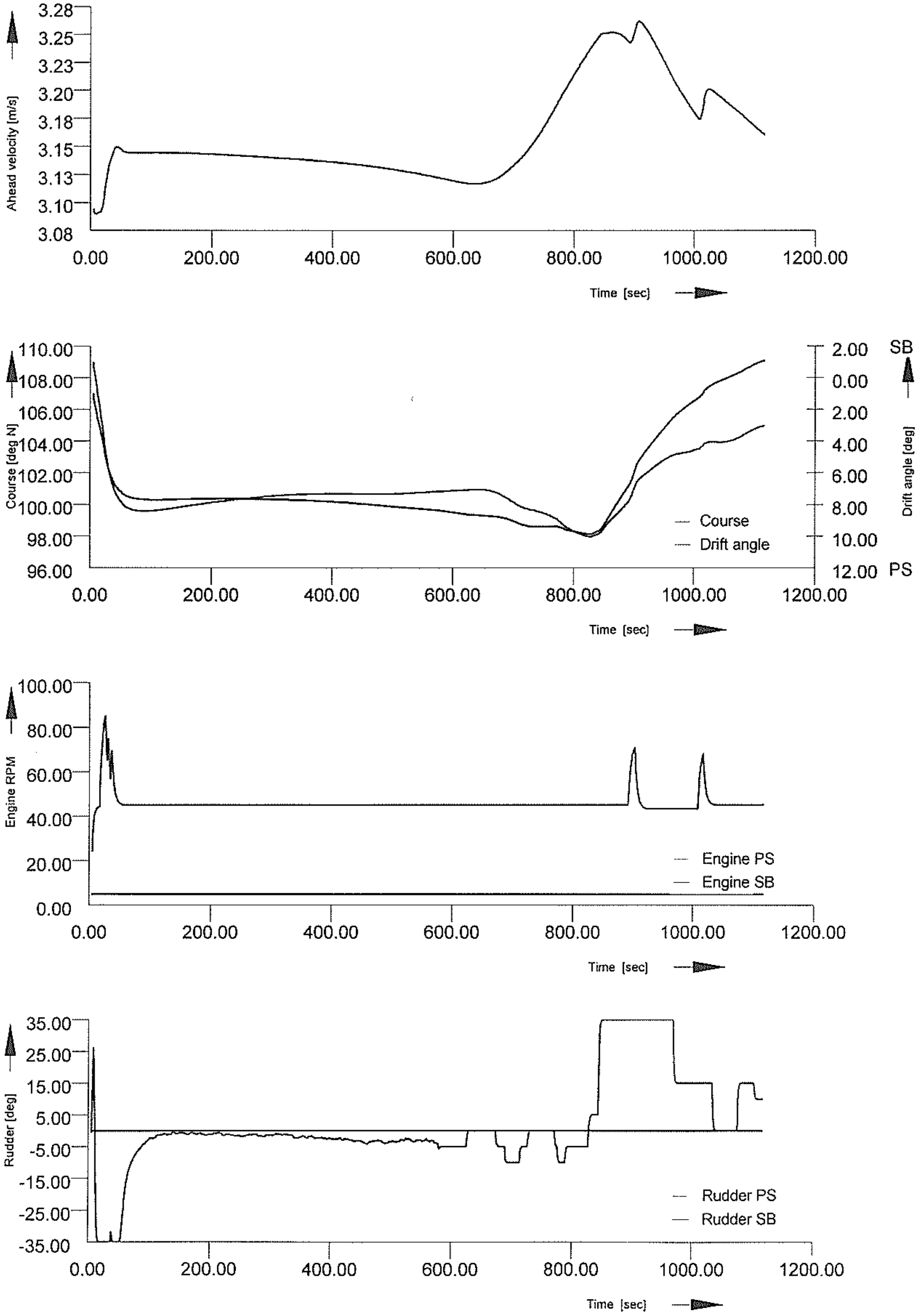




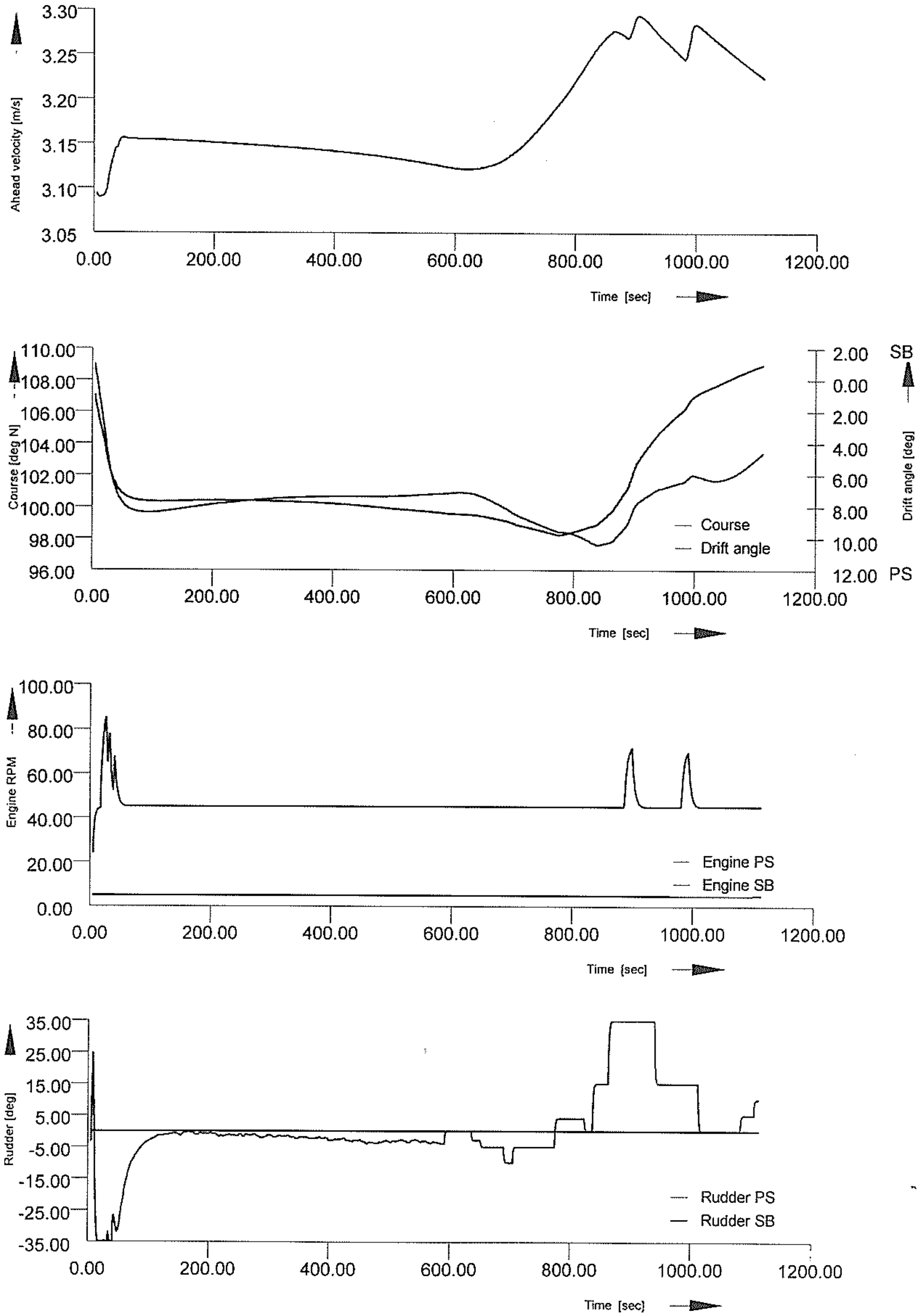


Real time Set I.2a Condition 44	R23	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

Alkyon 6/22/01 2:33:27 AM

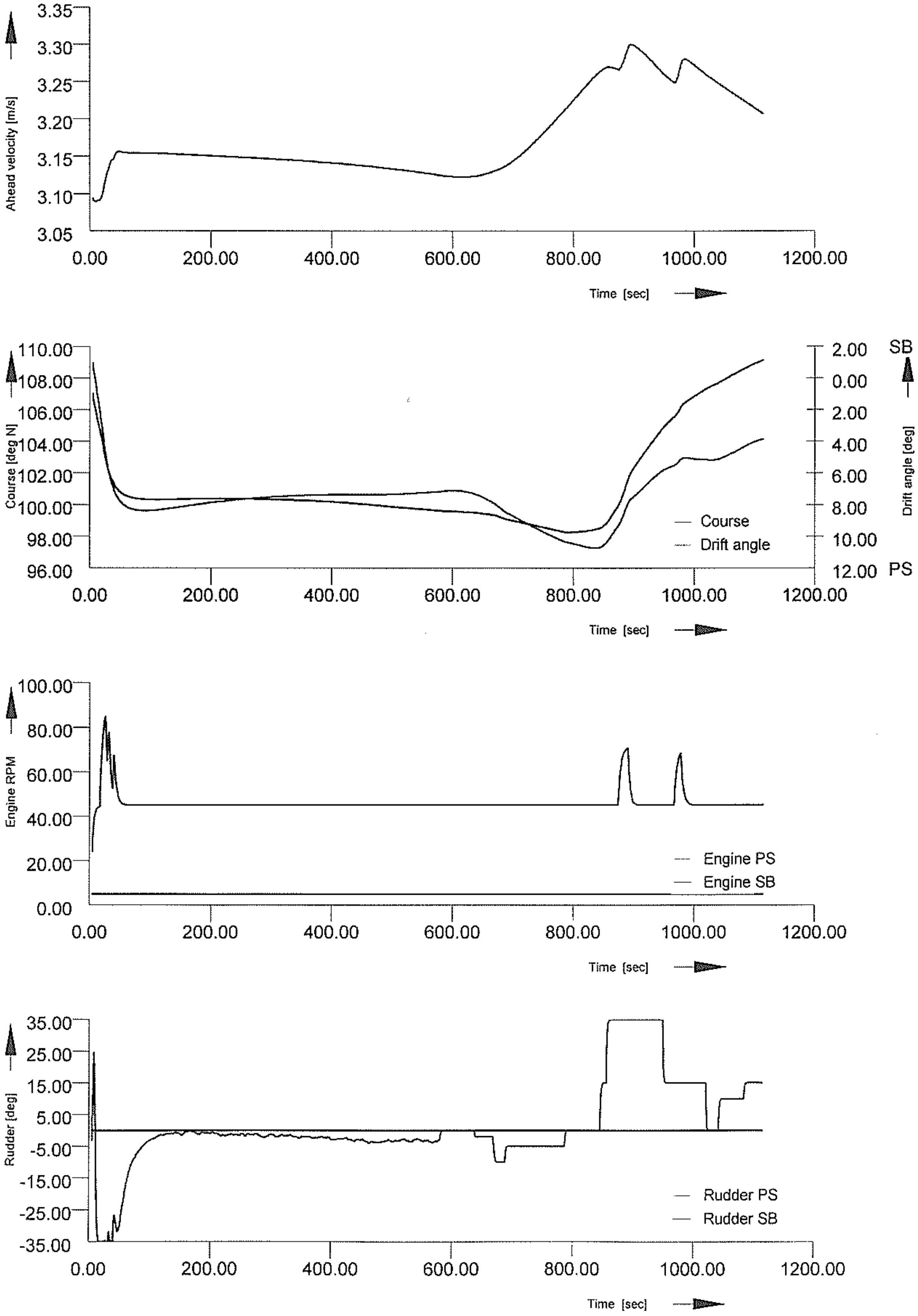


Real time Set I.2a Condition 44	R24 W. Welvaarts June 2001
AVV Transport Research Centre B010	



Real time Set I.2a Condition 44	R25 W. Welvaarts June 2001
AVV Transport Research Centre B010	

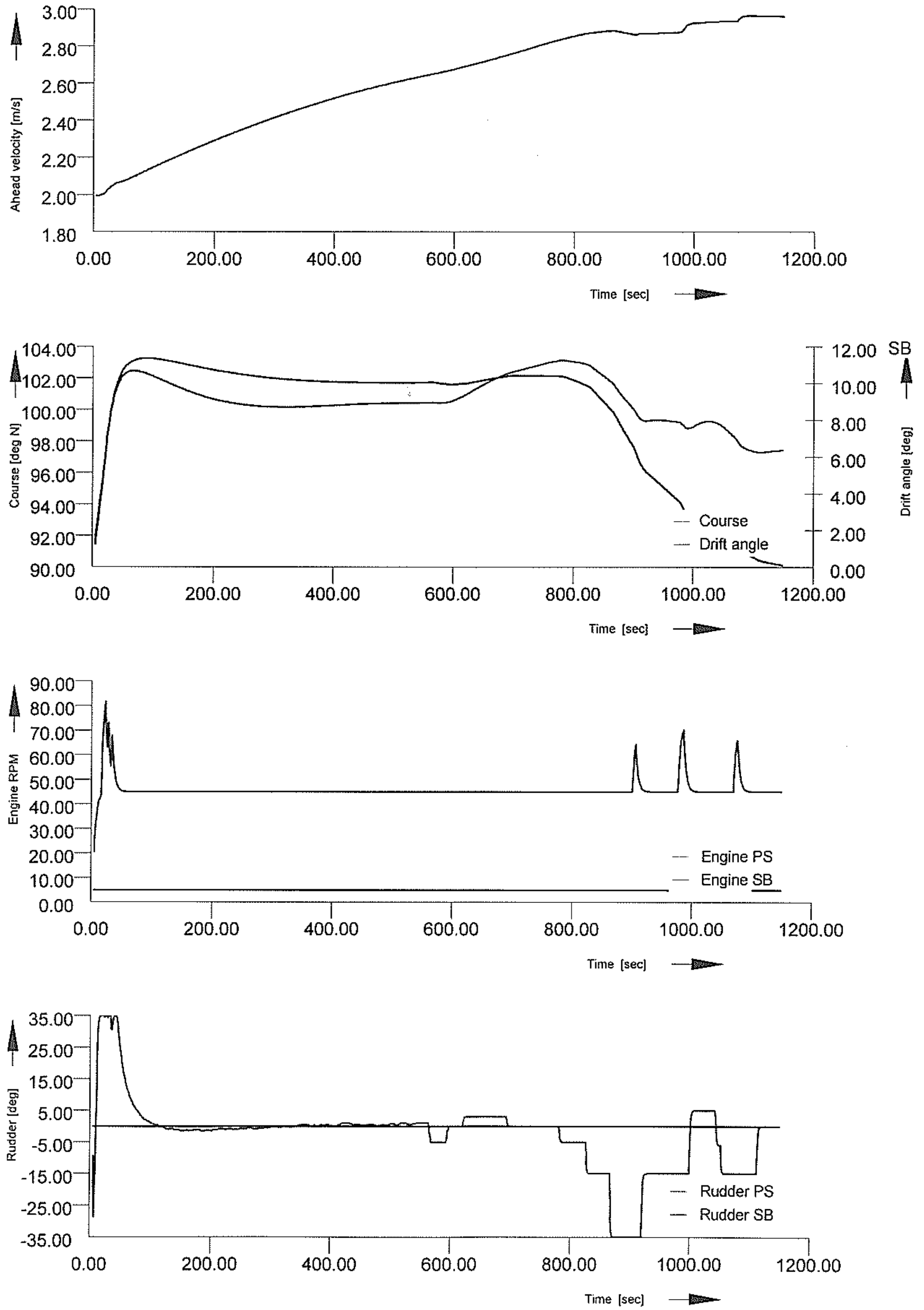
Alkyon 6/22/01 2:34:20 AM



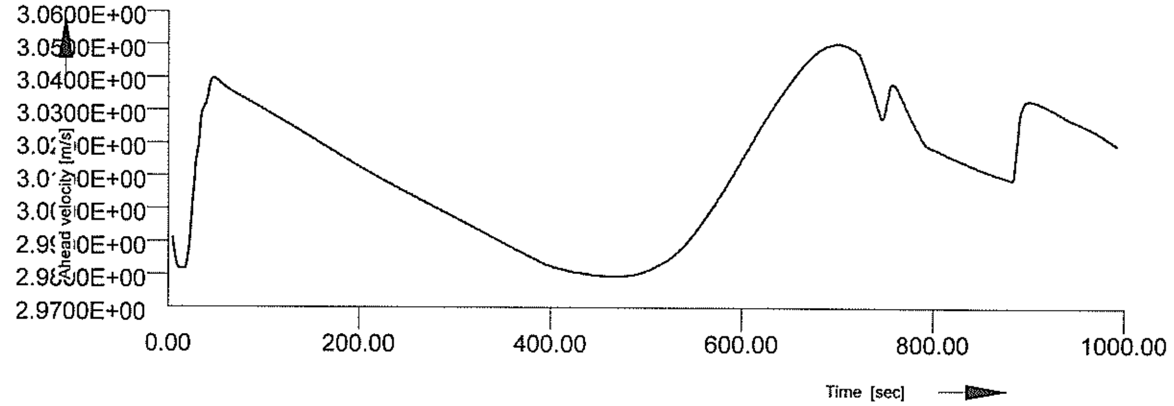
Real time Set I.2a Condition 44	R26	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

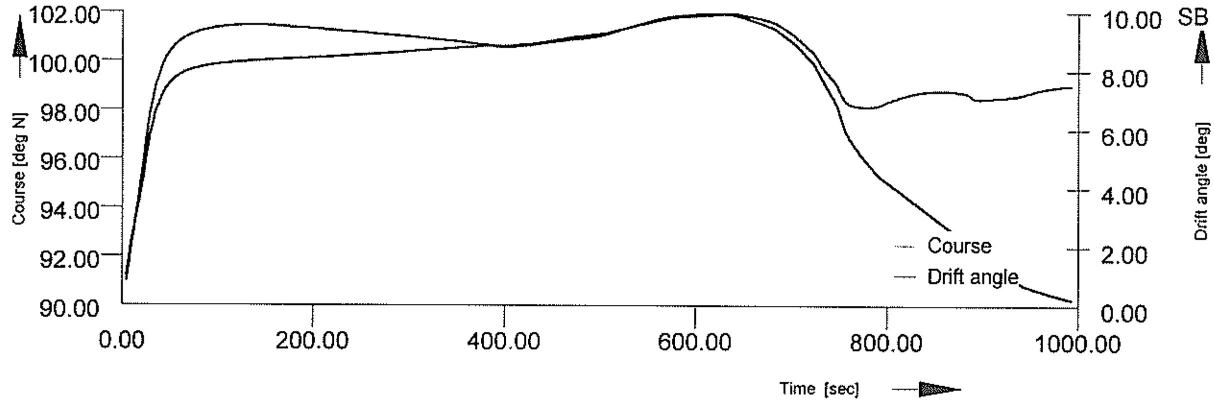
Appendix XVI.4: Real time runs condition 51

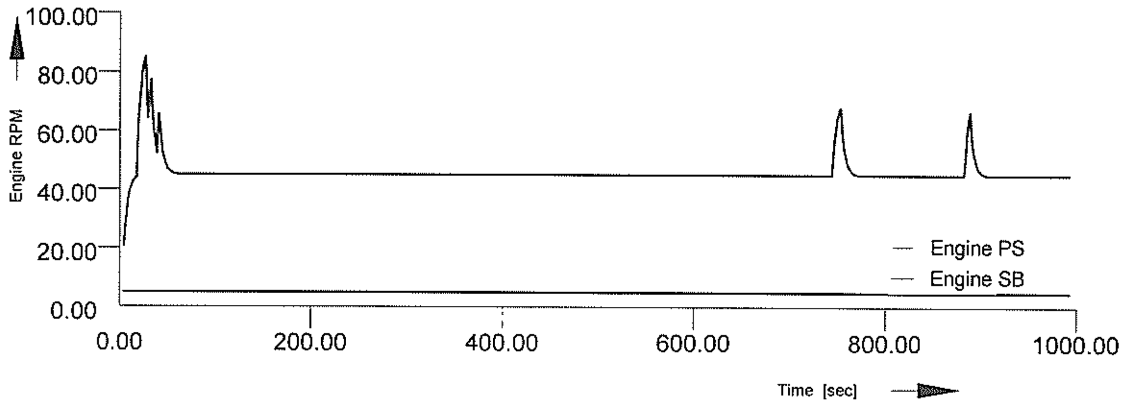
Alkyon 6/22/01 2:18:53 AM

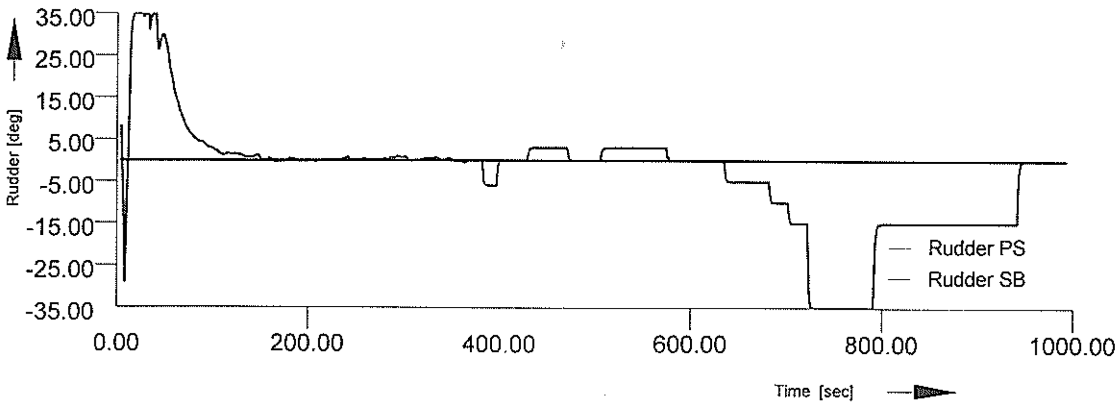


Real time Set I.2a Condition 51	R02 W. Welvaarts June 2001
AVV Transport Research Centre B010	

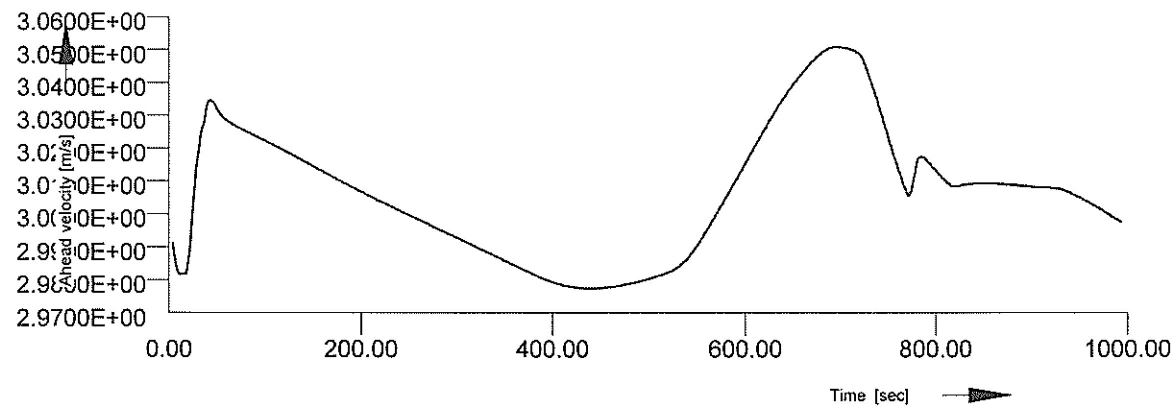


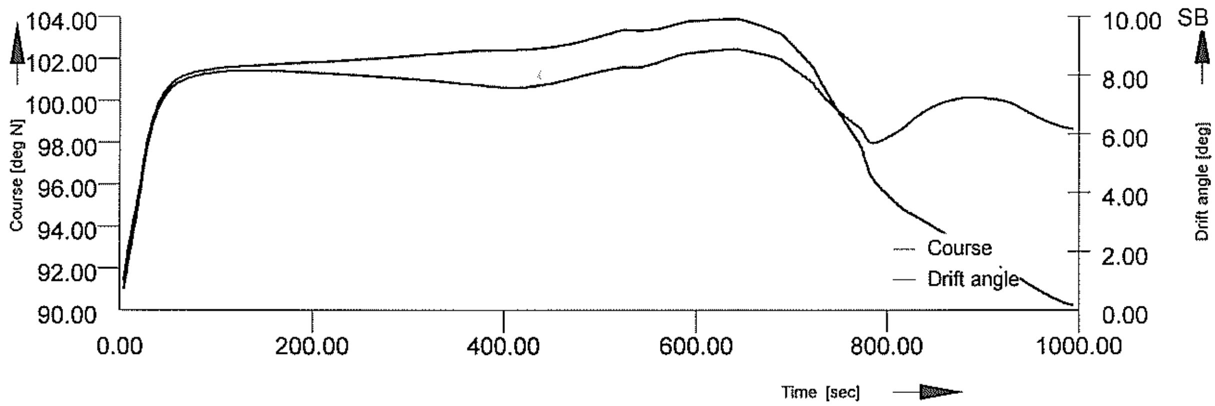


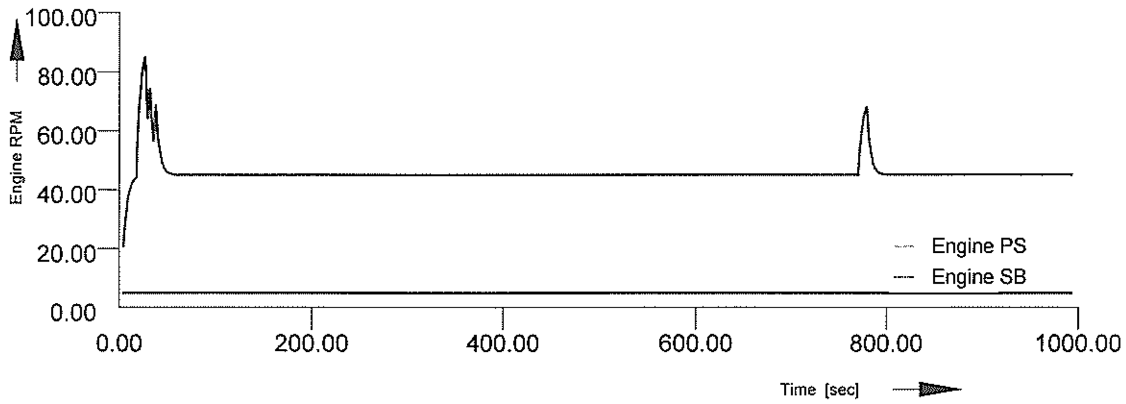


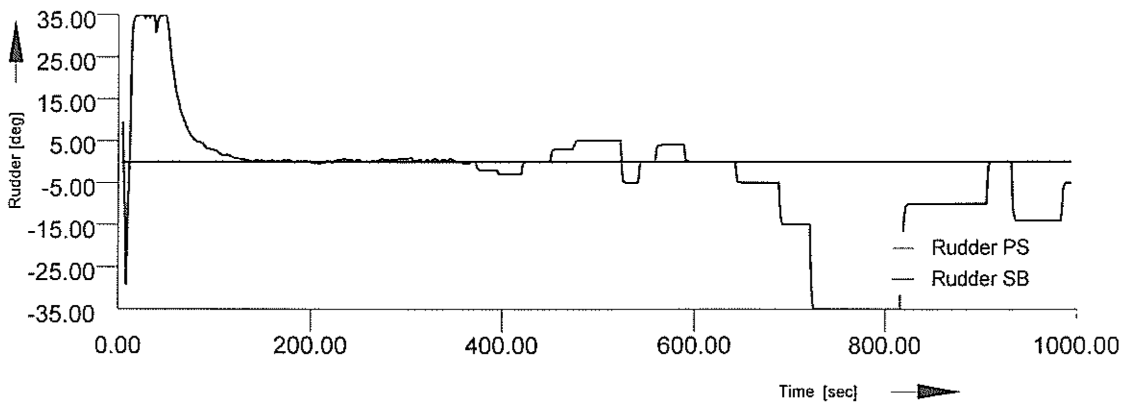


Real time Set I.2a Condition 51	R04 W. Welvaarts June 2001
AVV Transport Research Centre B010	

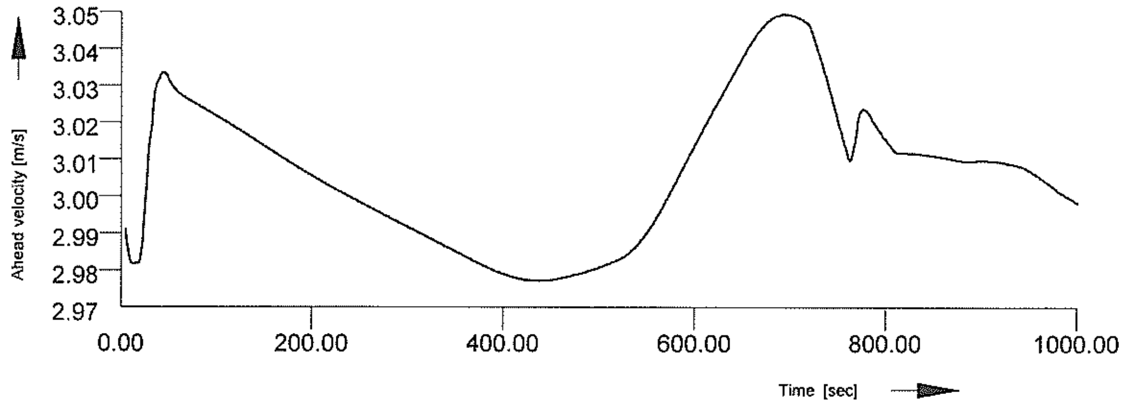


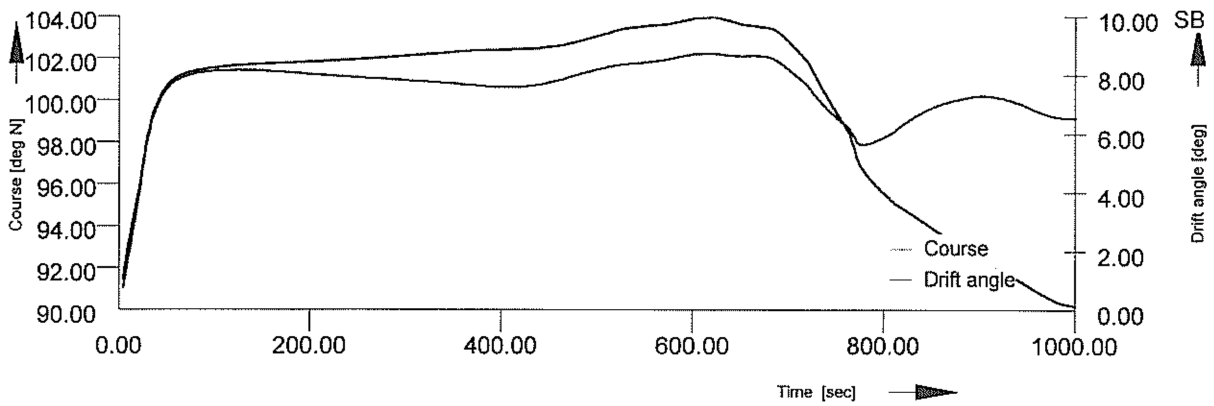


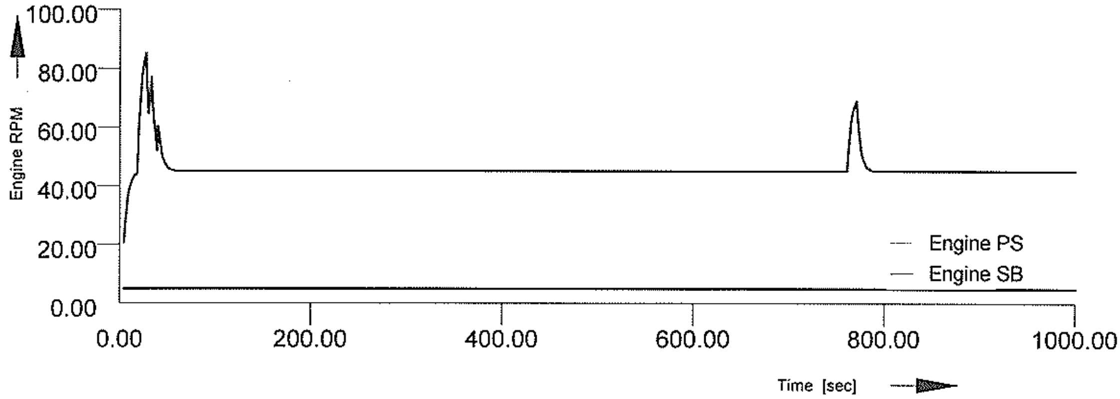


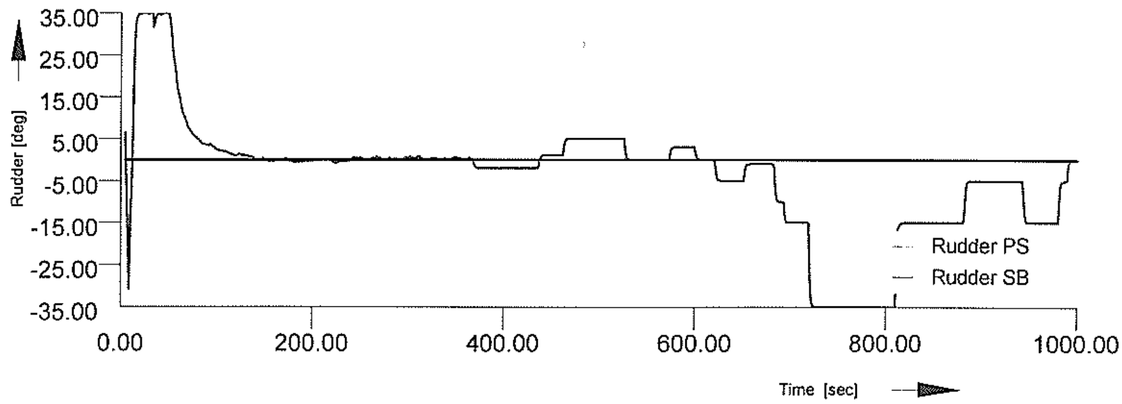


Real time Set I.2a Condition 51	R05 W. Welvaarts June 2001
AVV Transport Research Centre B010	

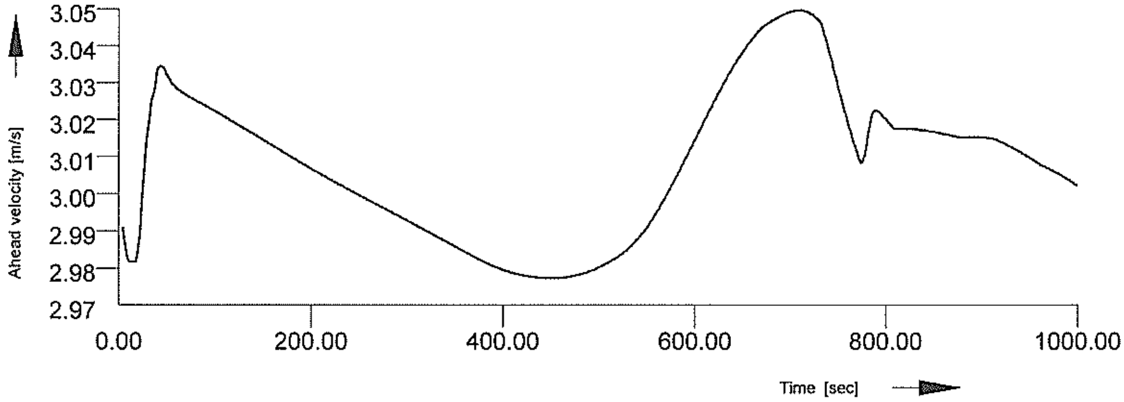


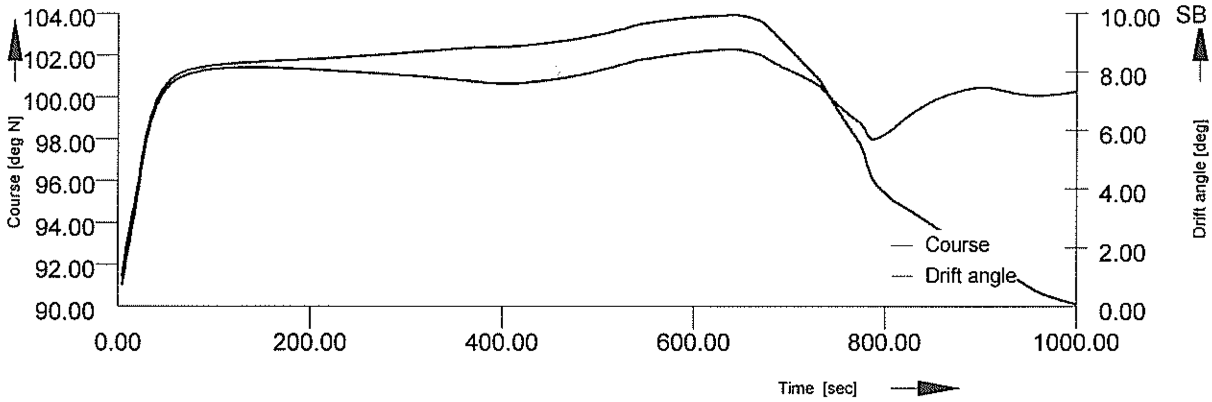


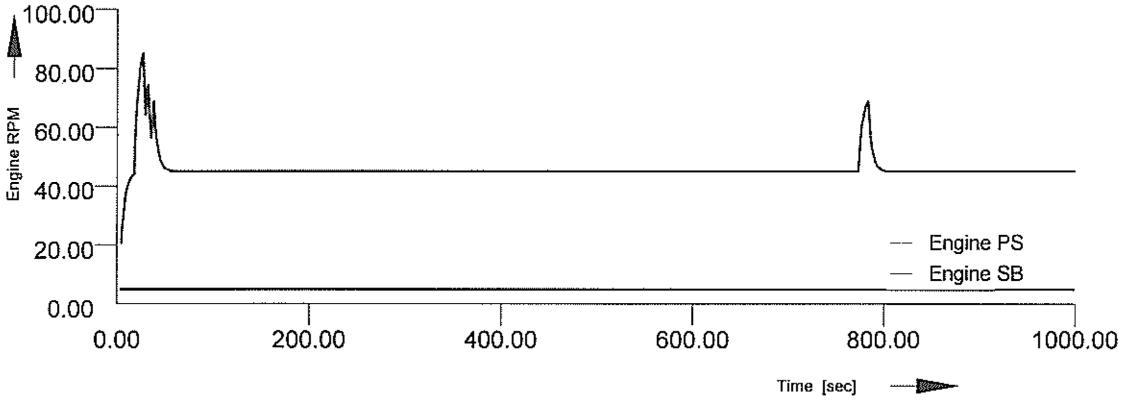


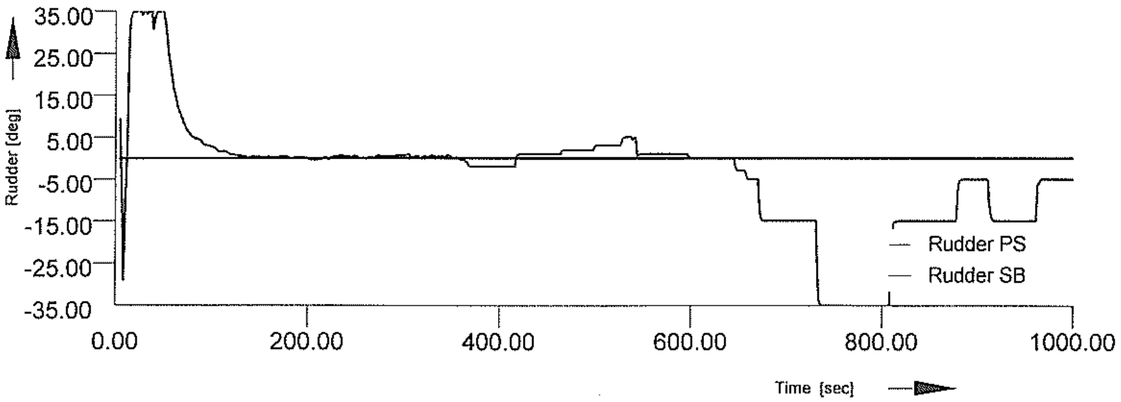


Real time Set I.2a Condition 51	R06 W. Welvaarts June 2001
AVV Transport Research Centre B010	



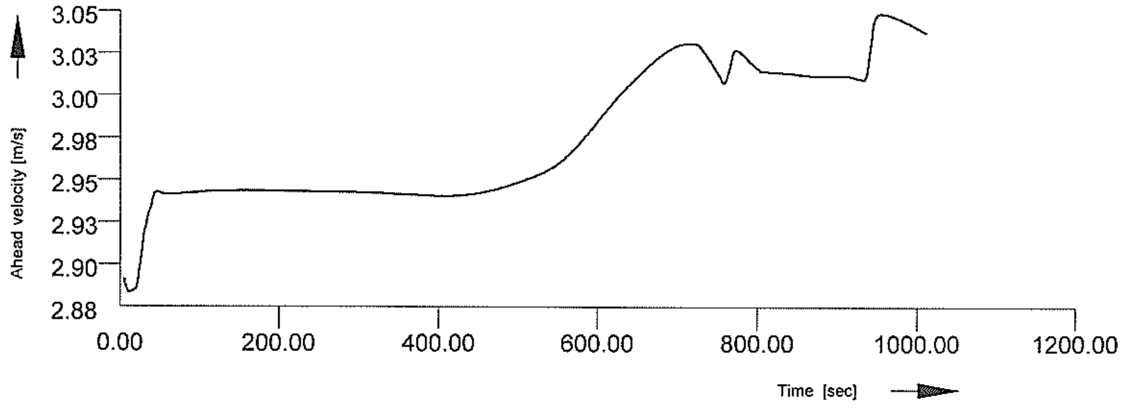


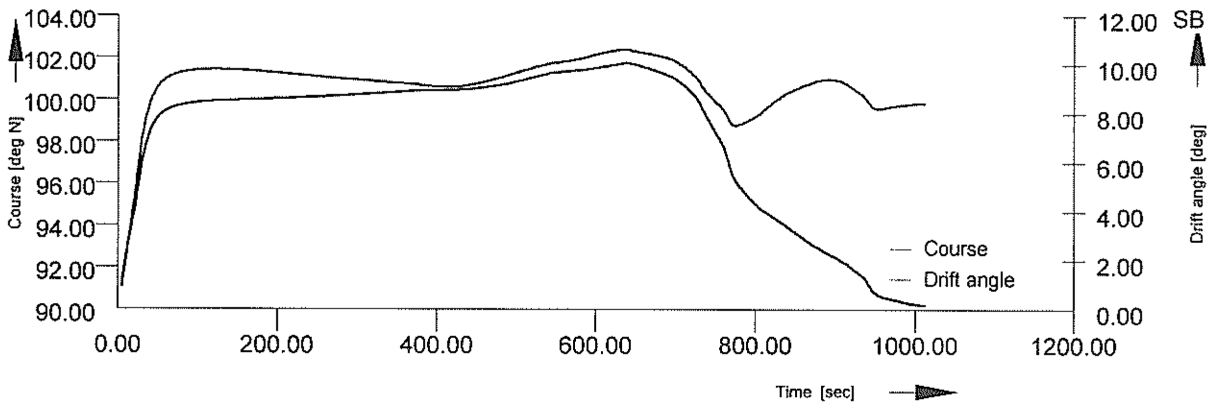


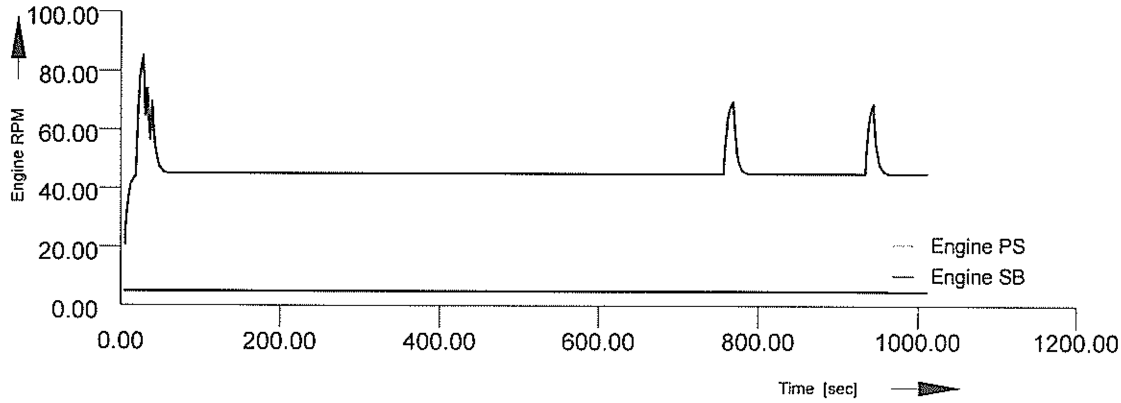


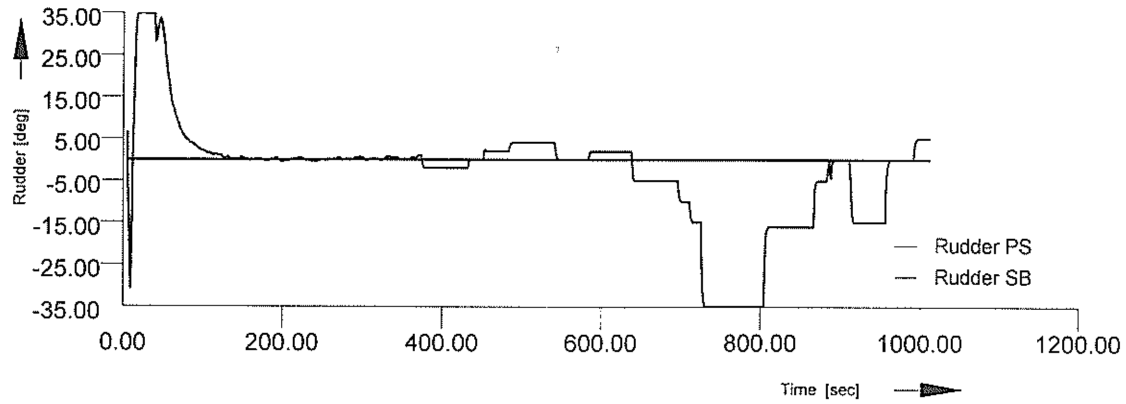
Real time Set I.2a Condition 51		R07 W. Welvaarts June 2001
AVV Transport Research Centre	B010	

Alkyon 6/22/01 2:40:51 AM



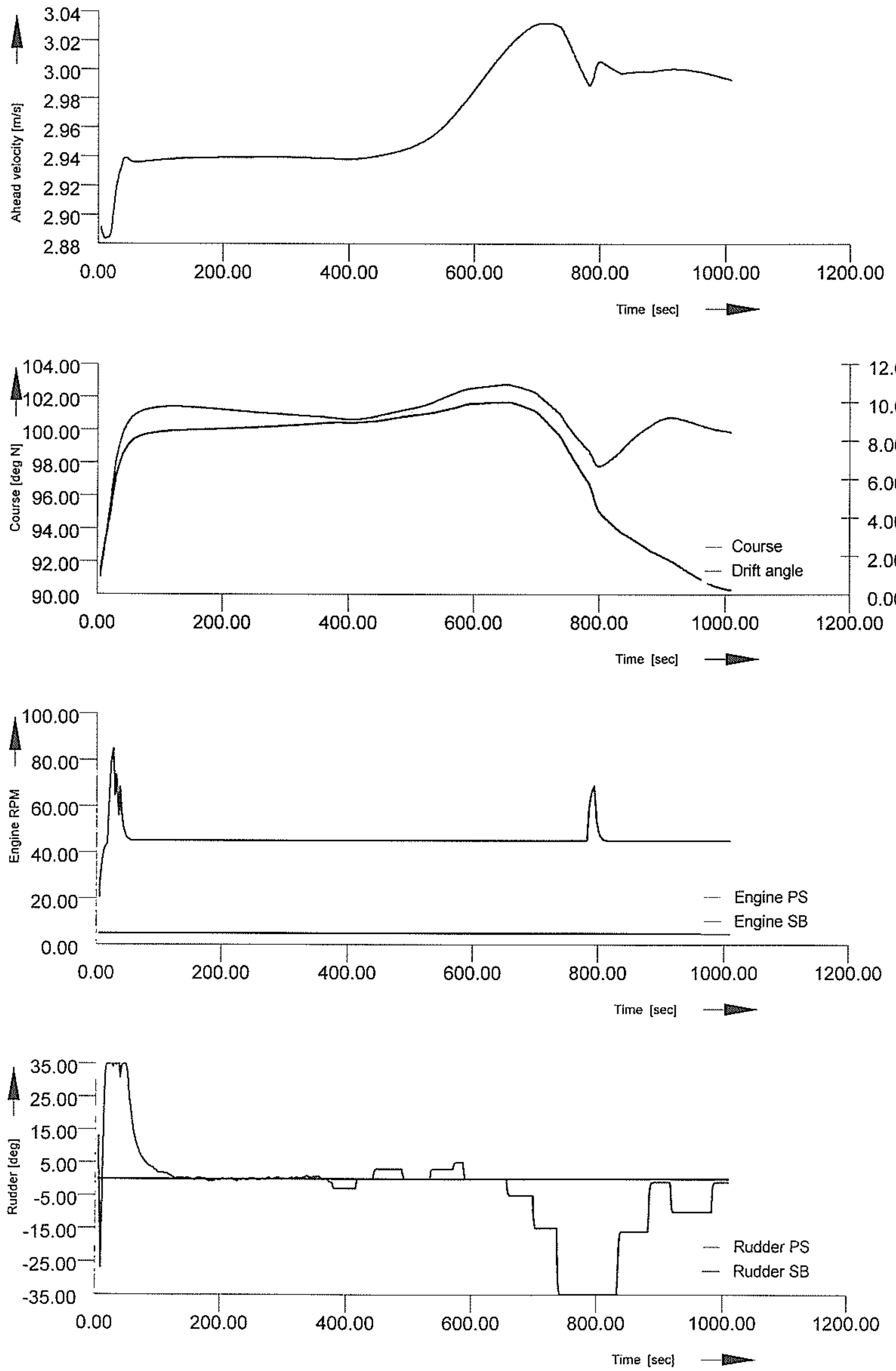




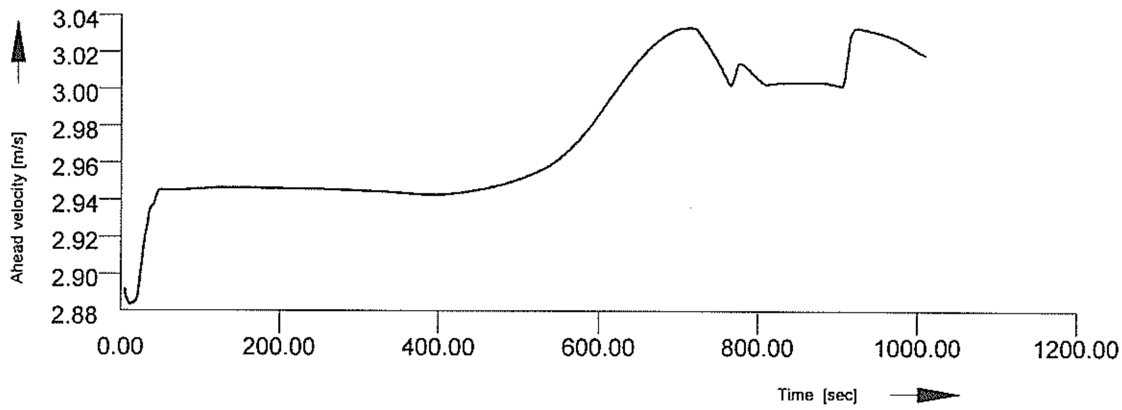


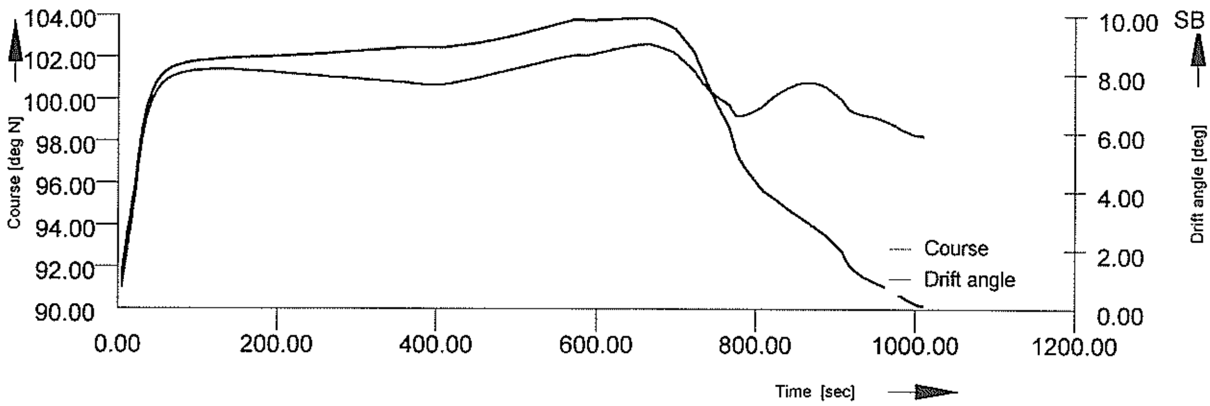
Real time Set I.2a Condition 51	R08 W. Welvaarts June 2001	
AVV Transport Research Centre	B010	

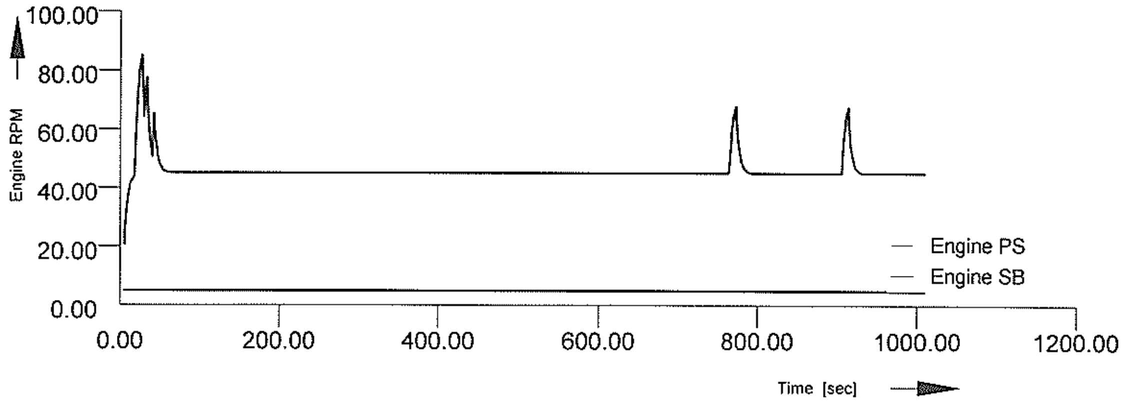
Alkyon 6/22/01 2.41.15 AM

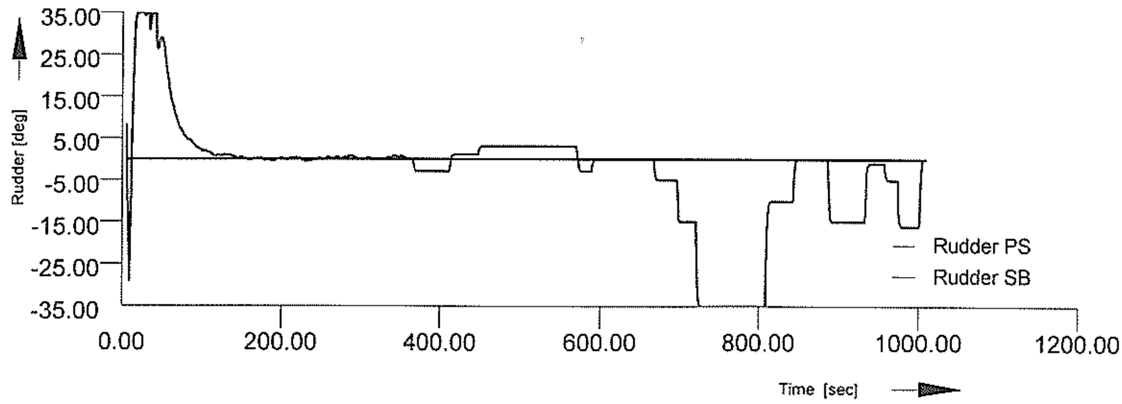


Real time Set I.2a Condition 51	R09 W. Welvaarts June 2001
AVV Transport Research Centre B010	

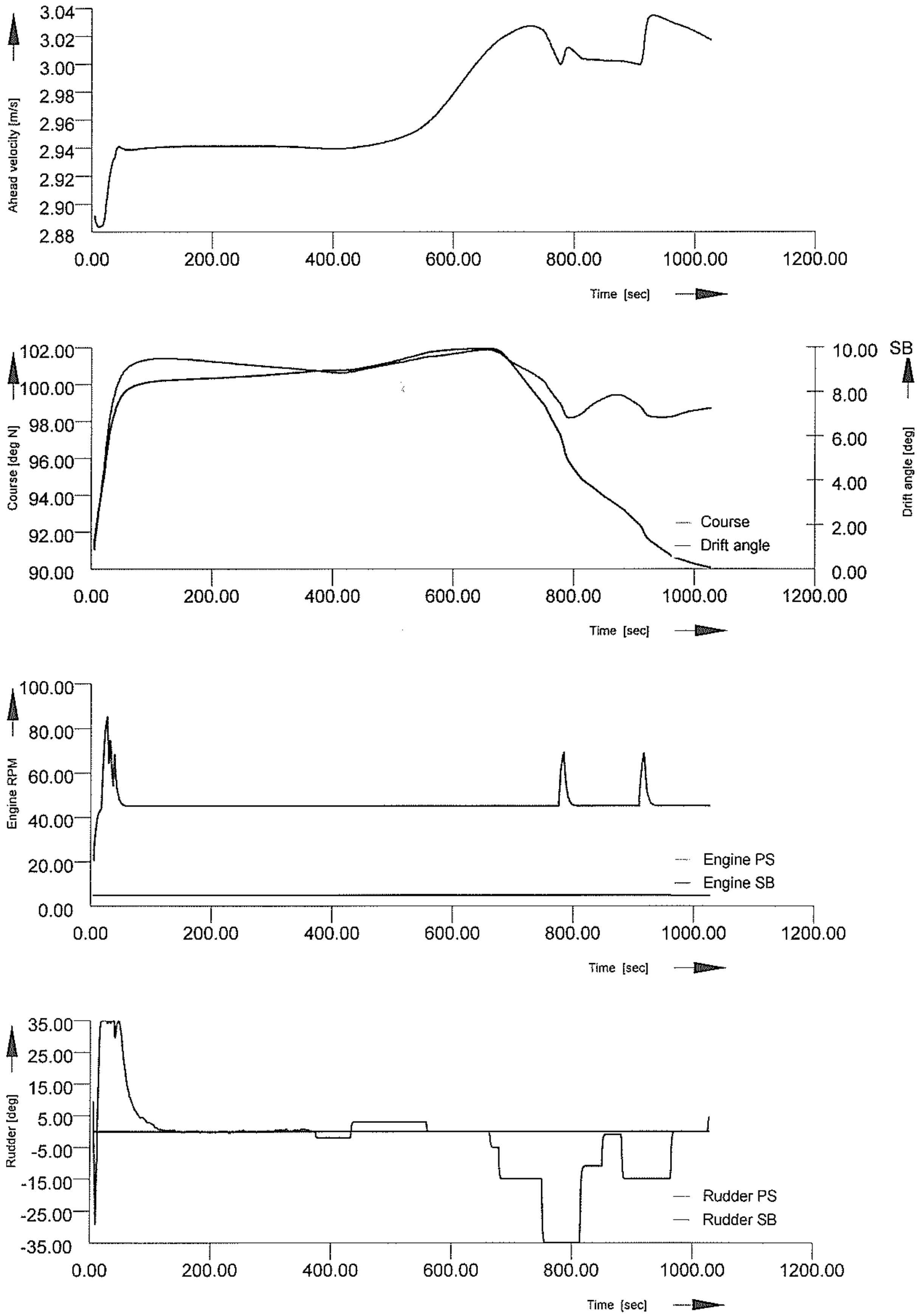






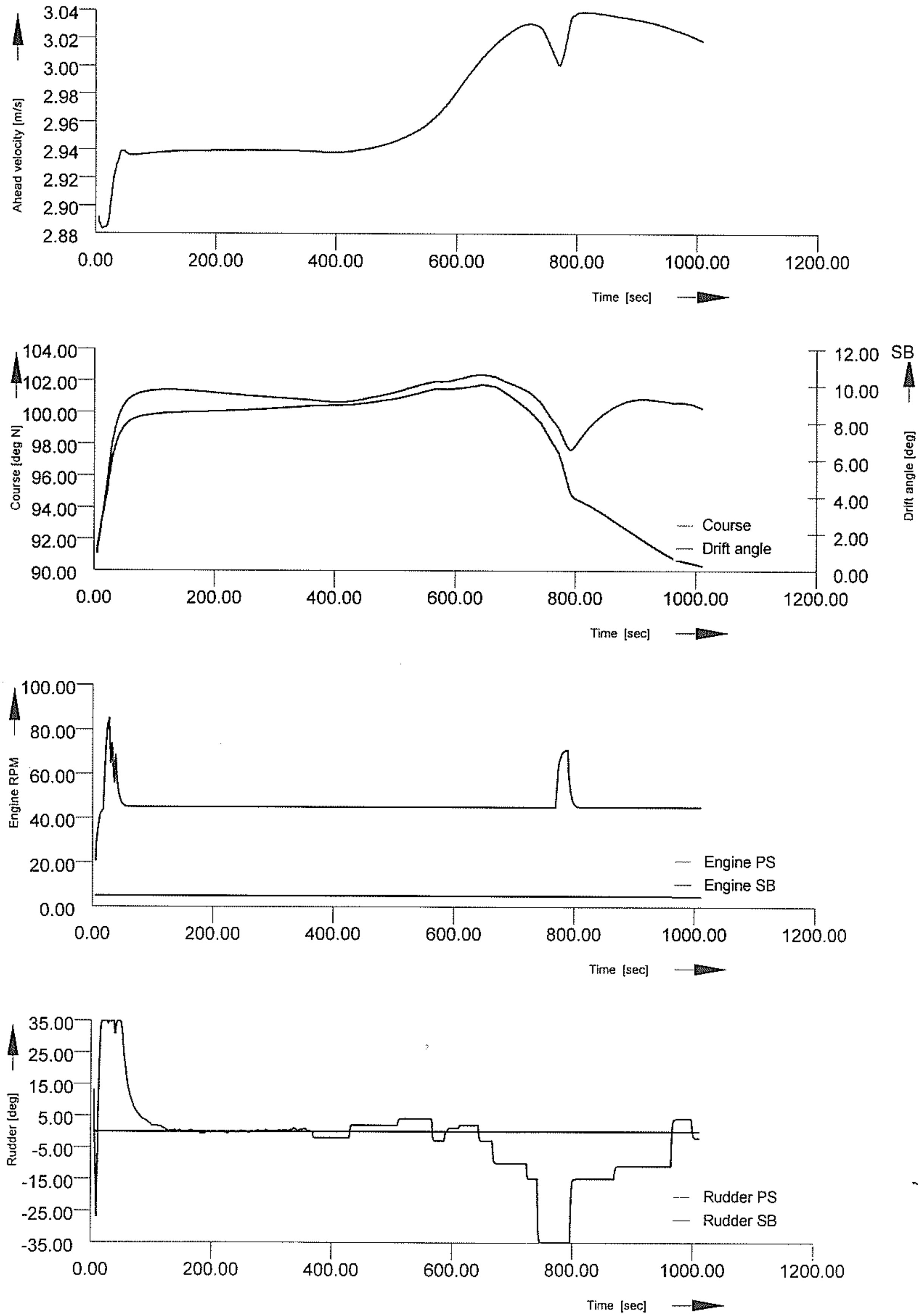


Real time Set I.2a Condition 51	R10 W. Welvaarts June 2001	
AVV Transport Research Centre	B010	



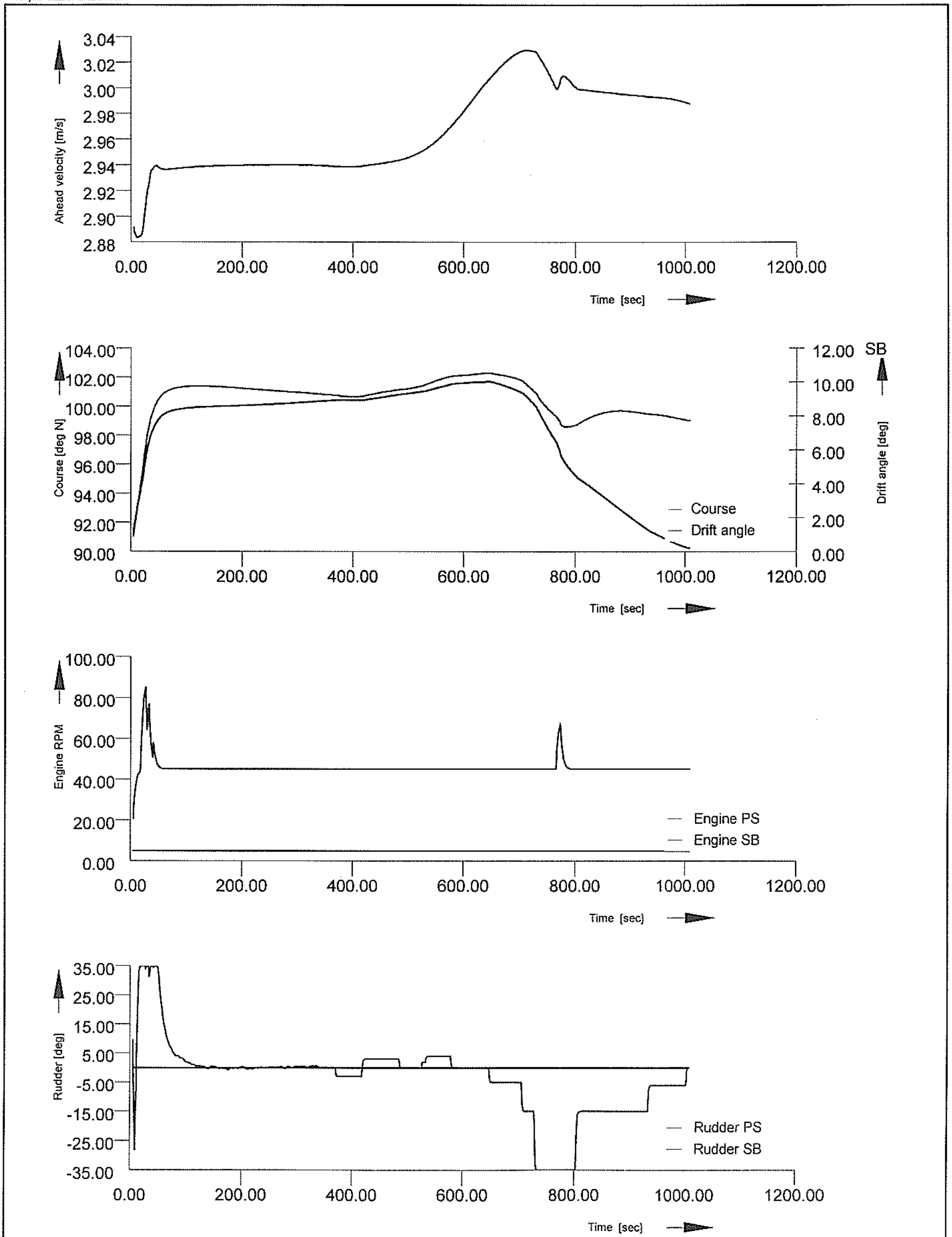
Real time Set I.2a Condition 51	R11 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 2:42:31 AM



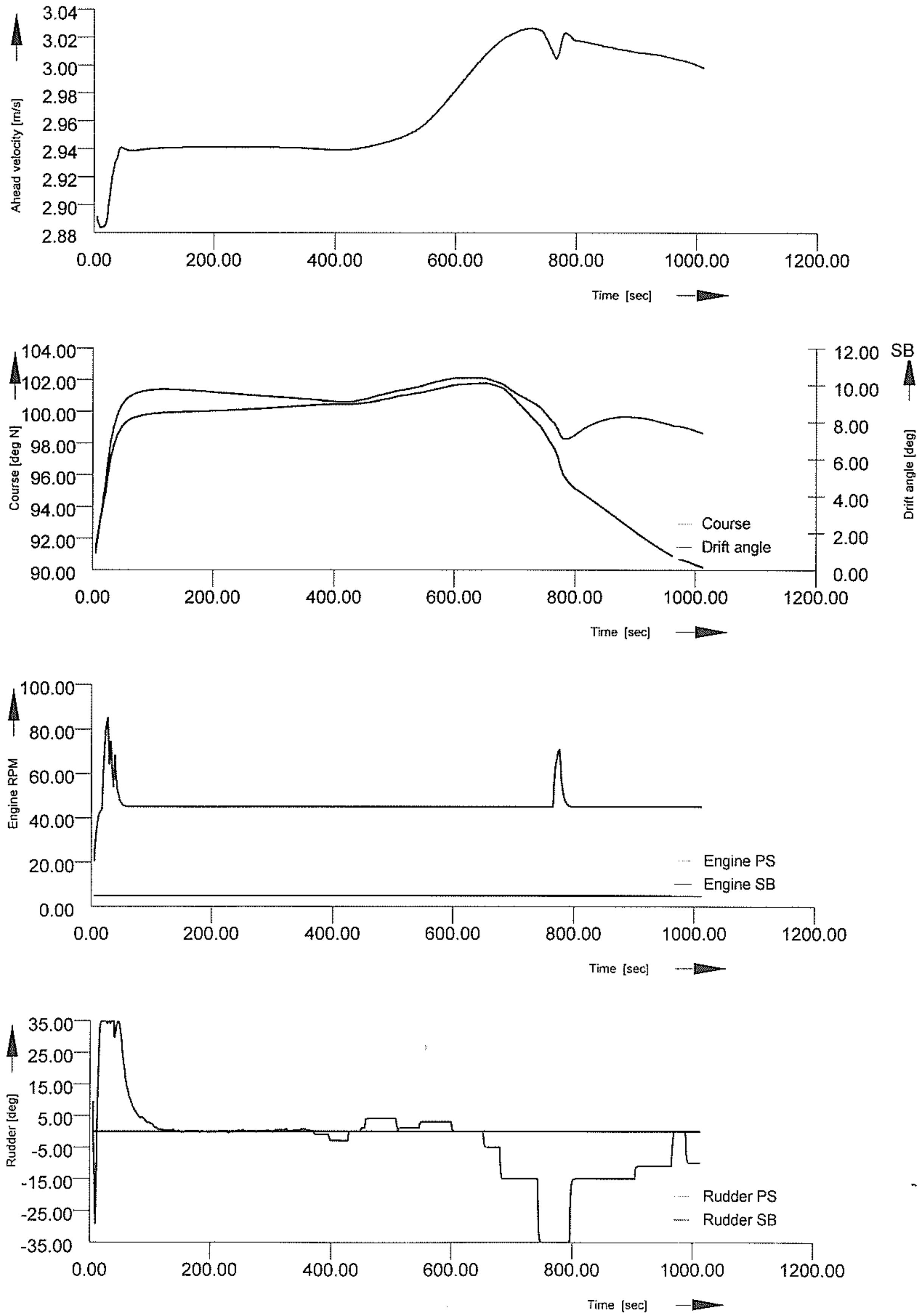
Real time Set I.2a Condition 51	R12	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

Alkyon 6/22/01 2:42:54 AM



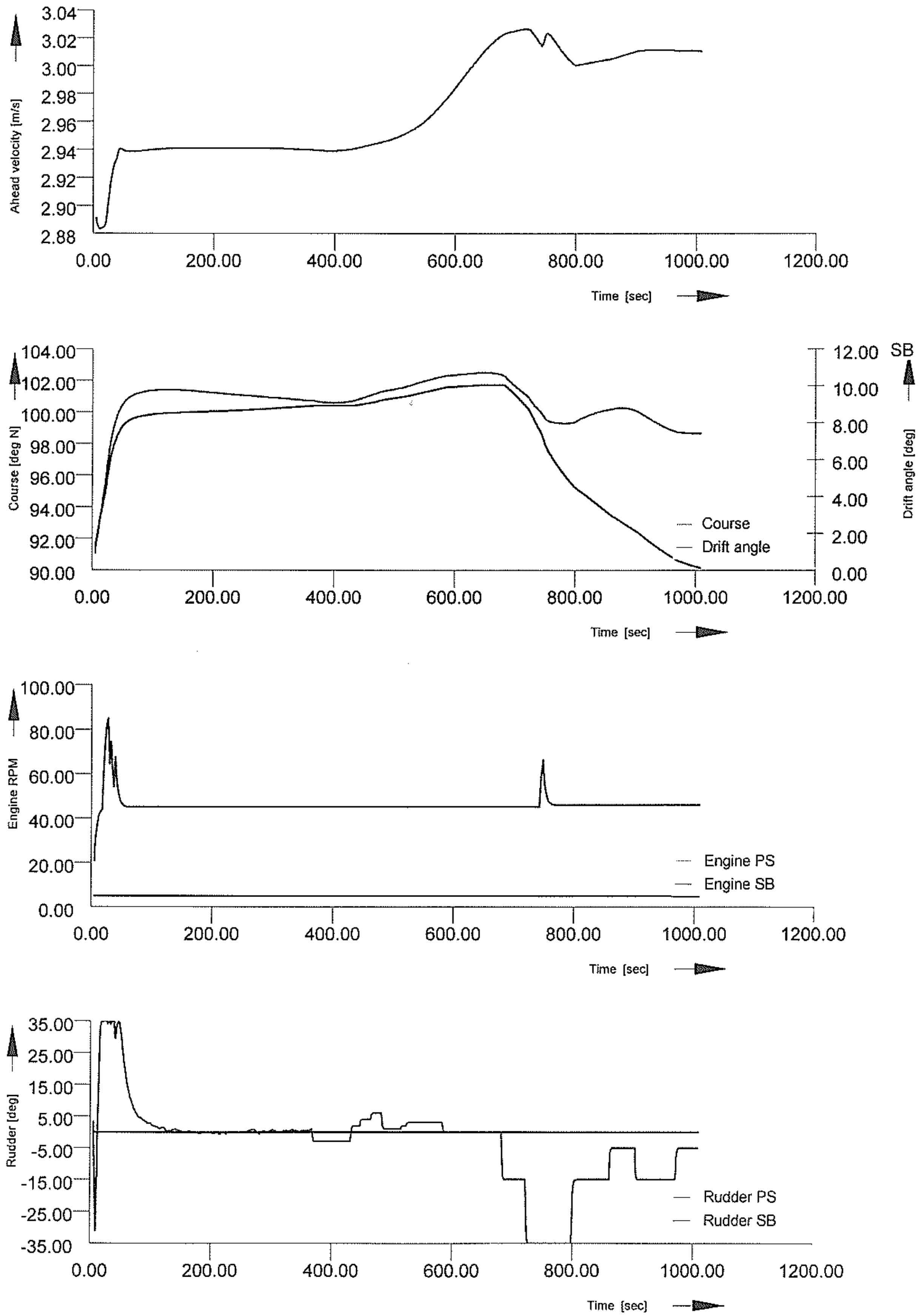
Real time Set I.2a Condition 51	R13 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 2:43:22 AM

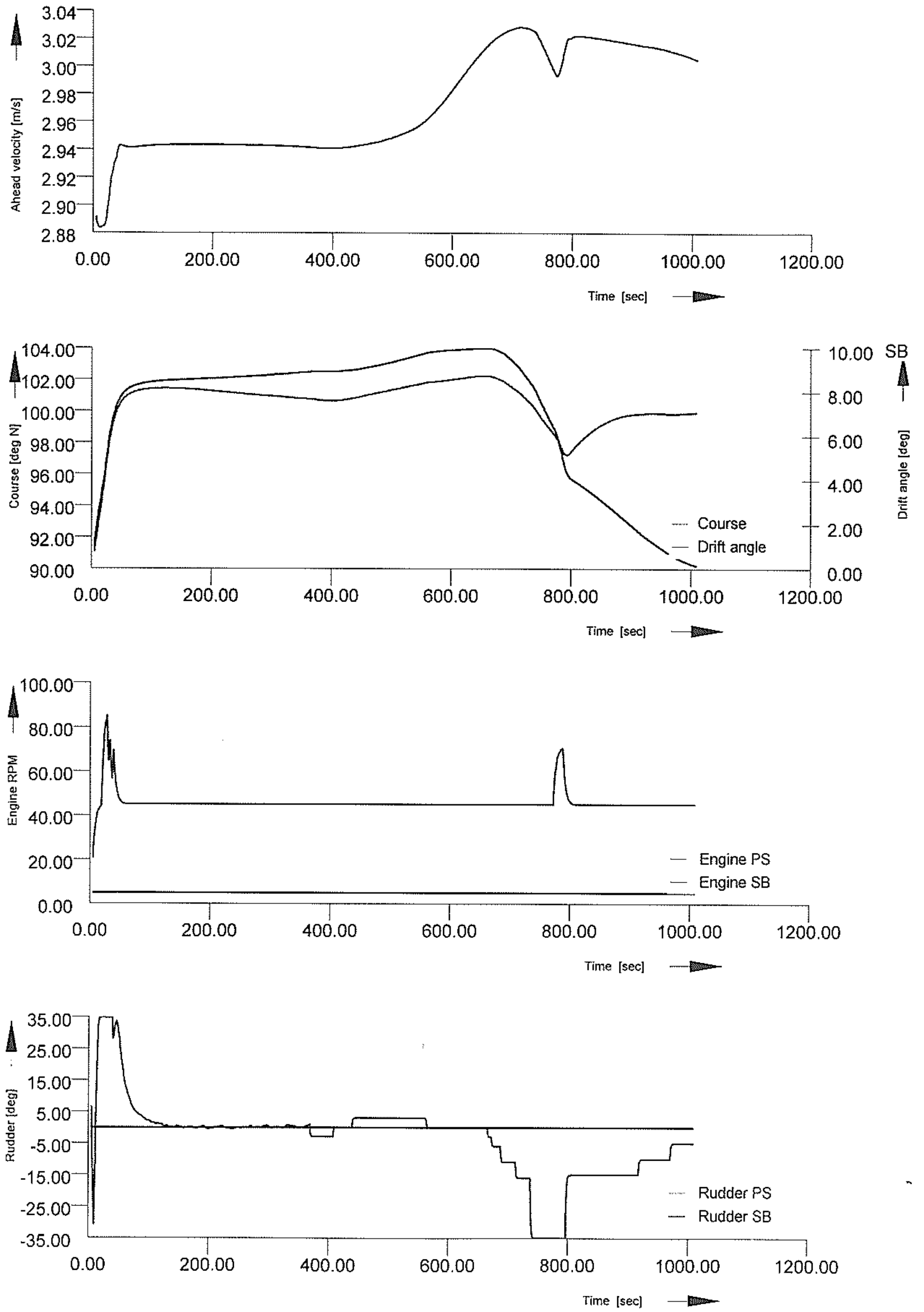


Real time Set I.2a Condition 51	R14 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 2:43:46 AM

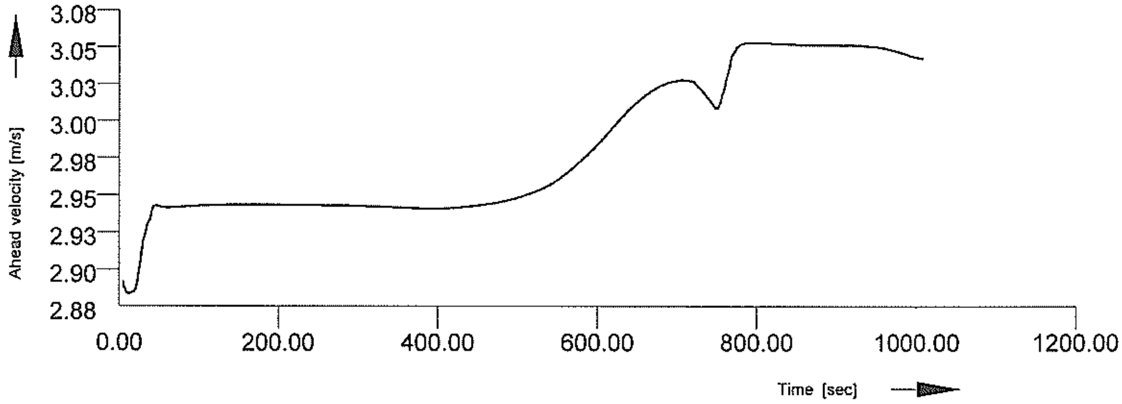


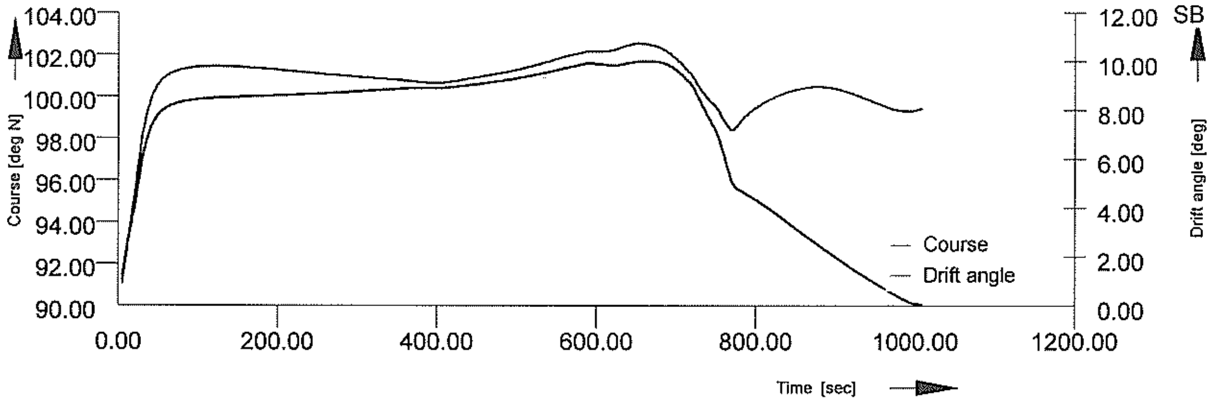
Real time Set I.2a Condition 51	R15 W. Welvaarts June 2001
AVV Transport Research Centre B010	

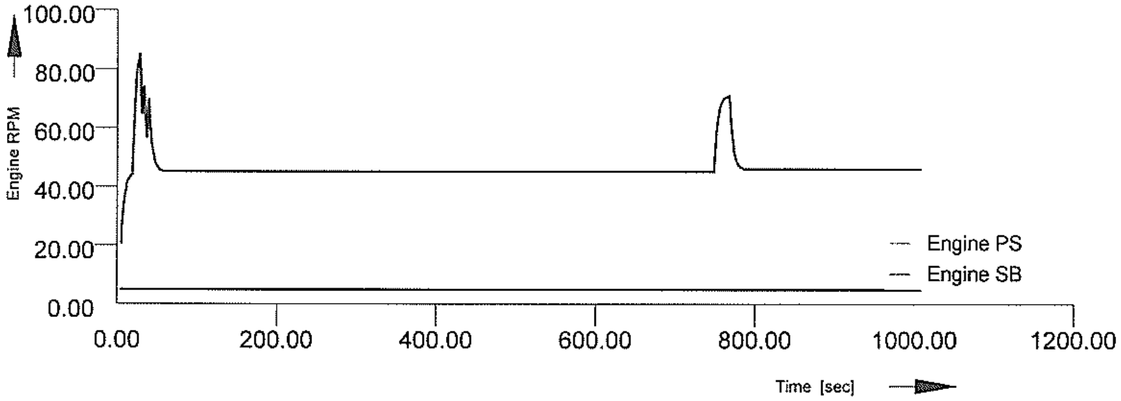


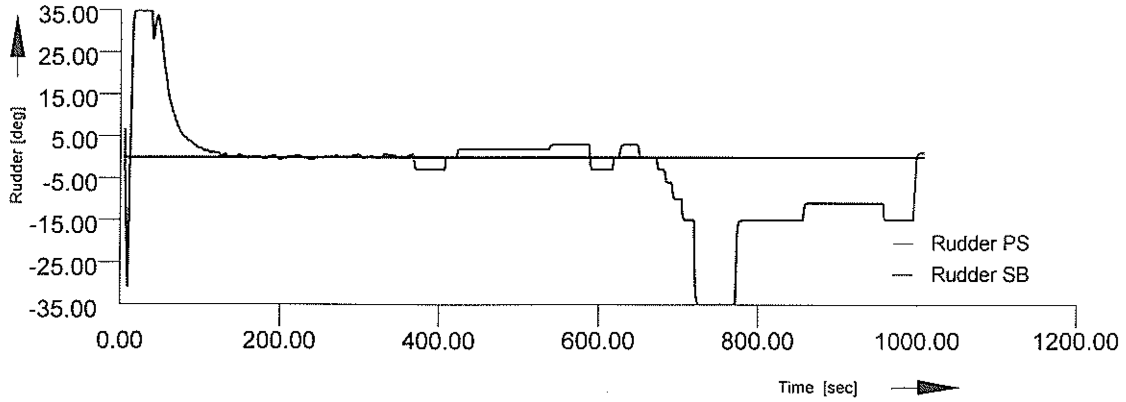
Real time Set I.2a Condition 51	R16	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

Alkyon 6/22/01 2:46:48 AM

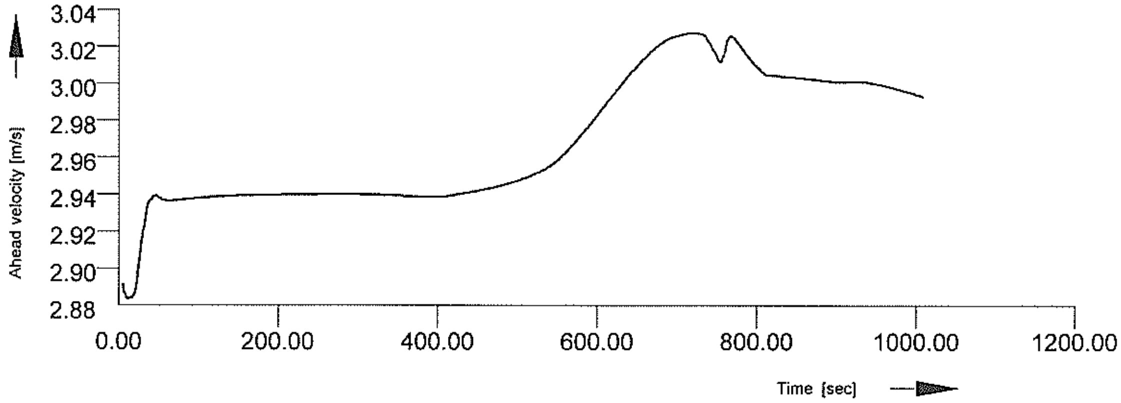


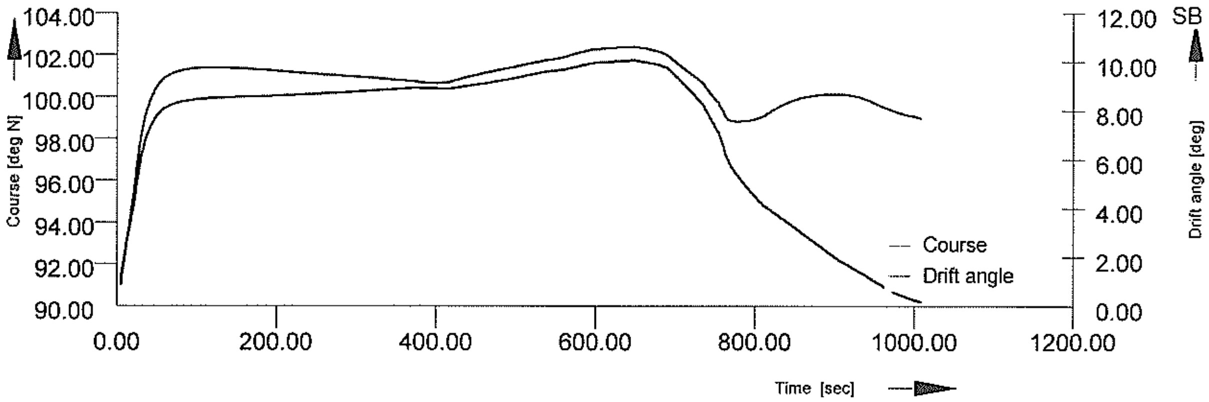


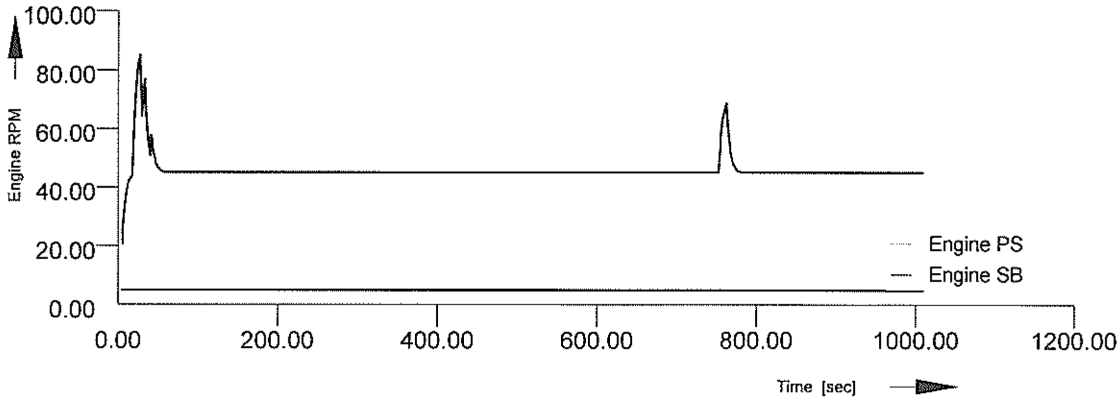


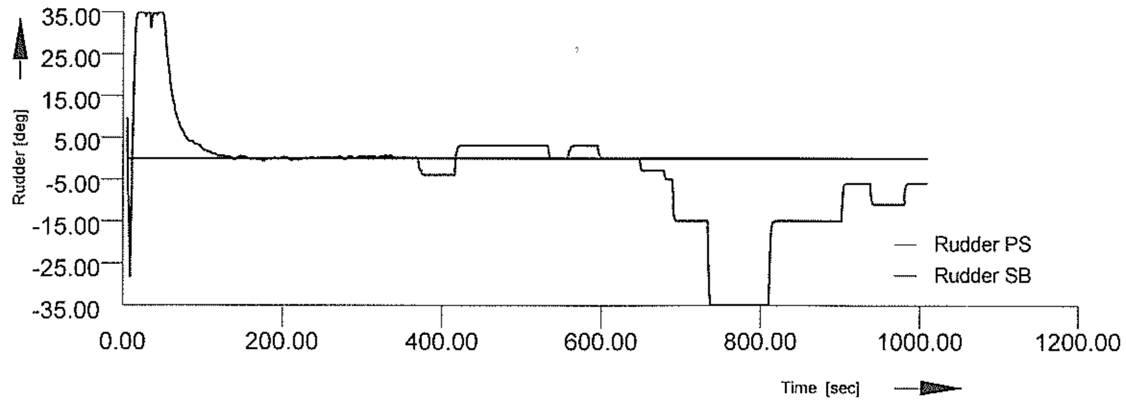


Real time Set I.2a Condition 51	R17	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre B010		

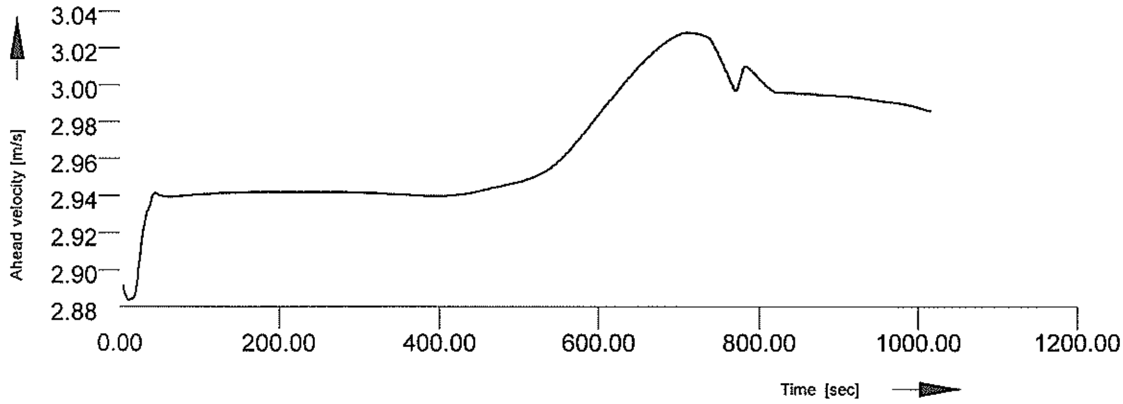


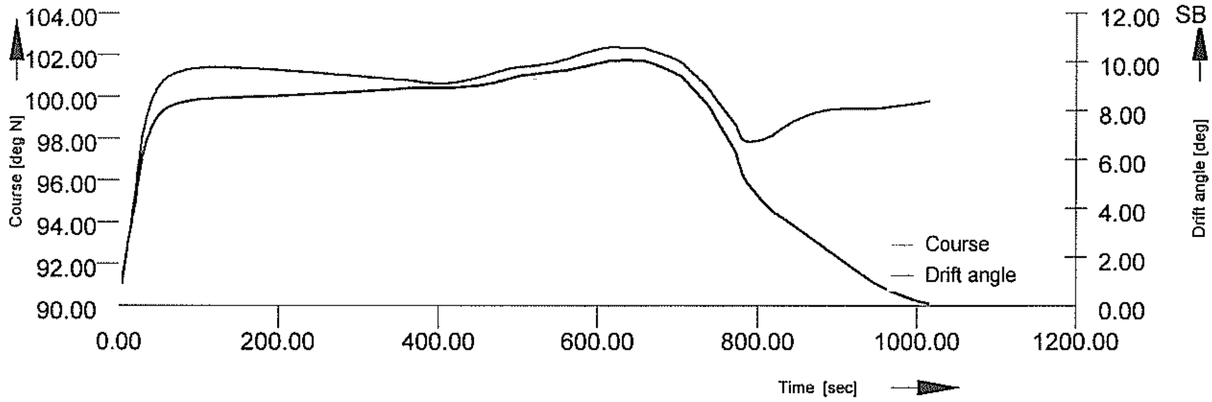


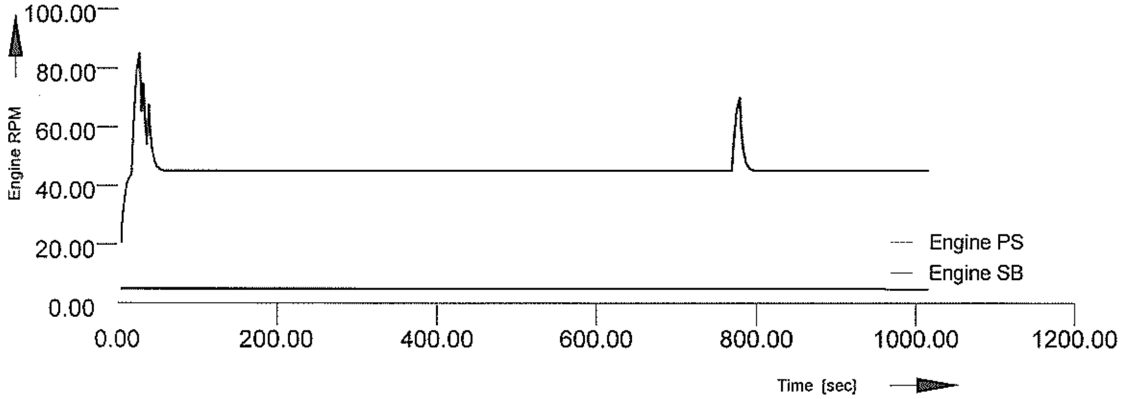


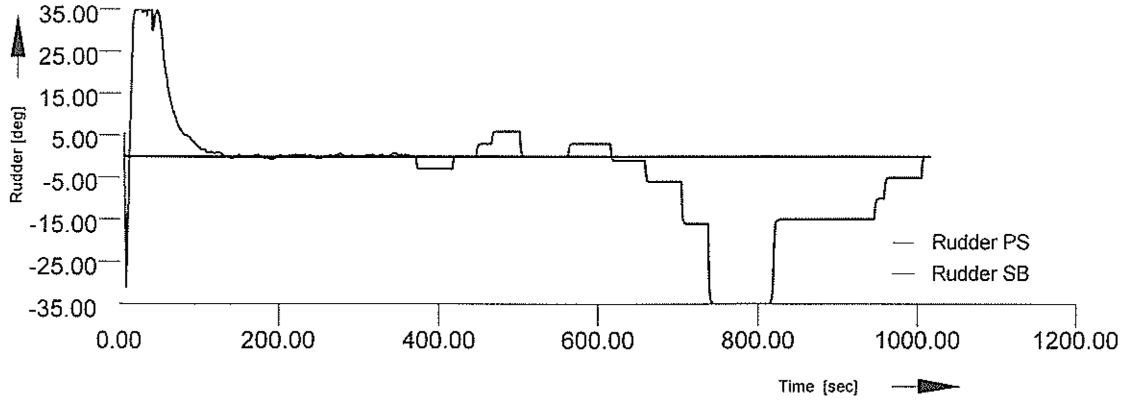


Real time Set I.2a Condition 51	R18 W. Welvaarts June 2001
AVV Transport Research Centre B010	

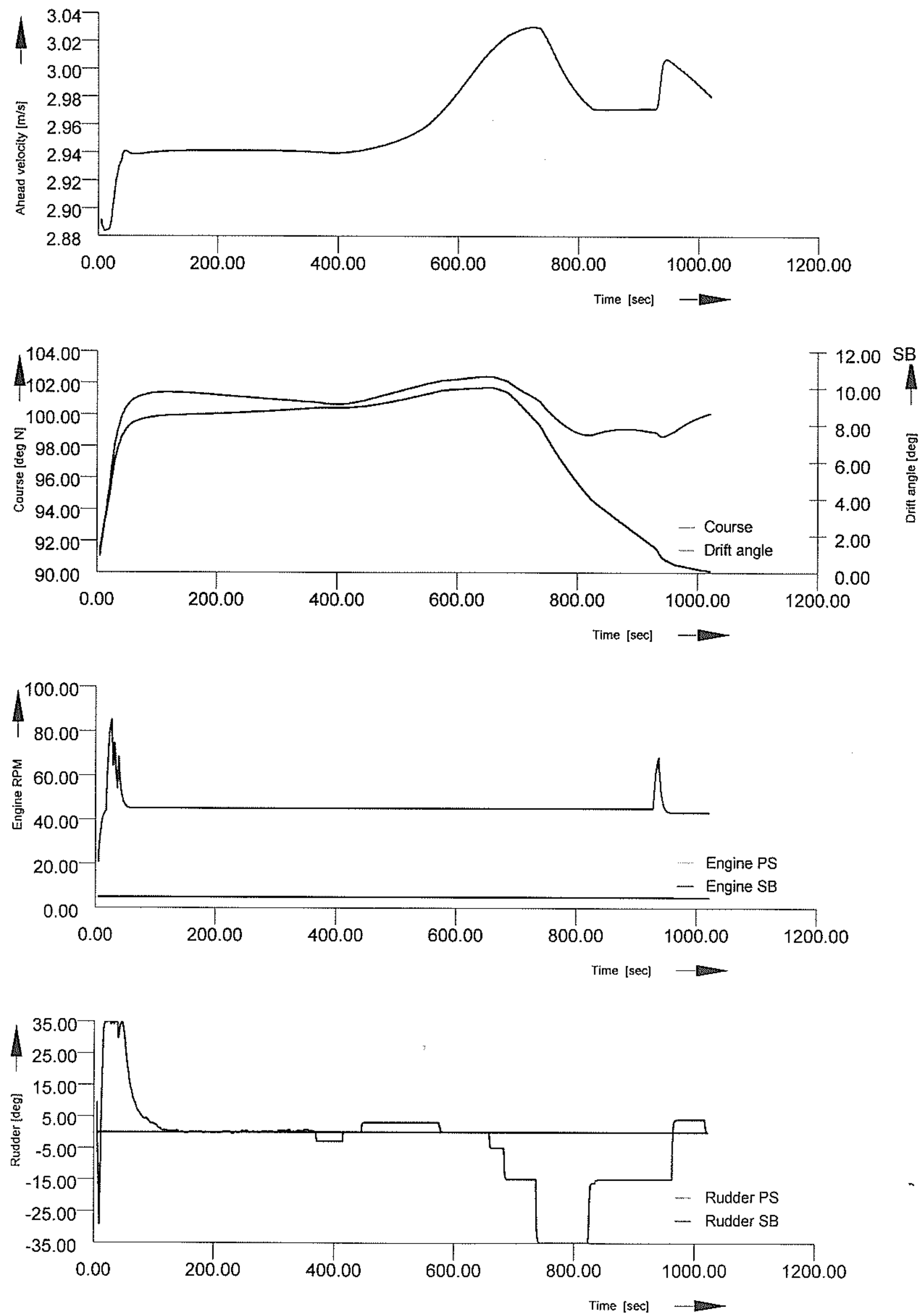






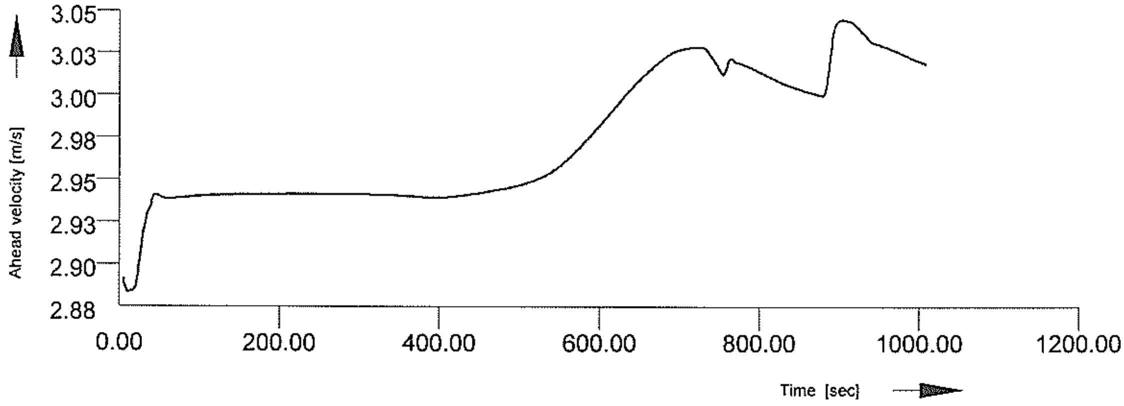


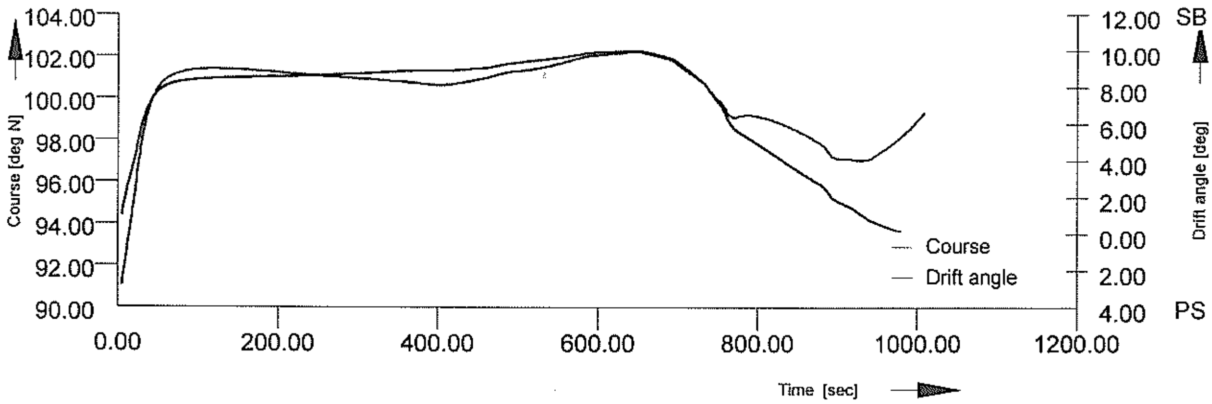
Real time Set I.2a Condition 51	R19 W. Welvaarts June 2001
AVV Transport Research Centre B010	

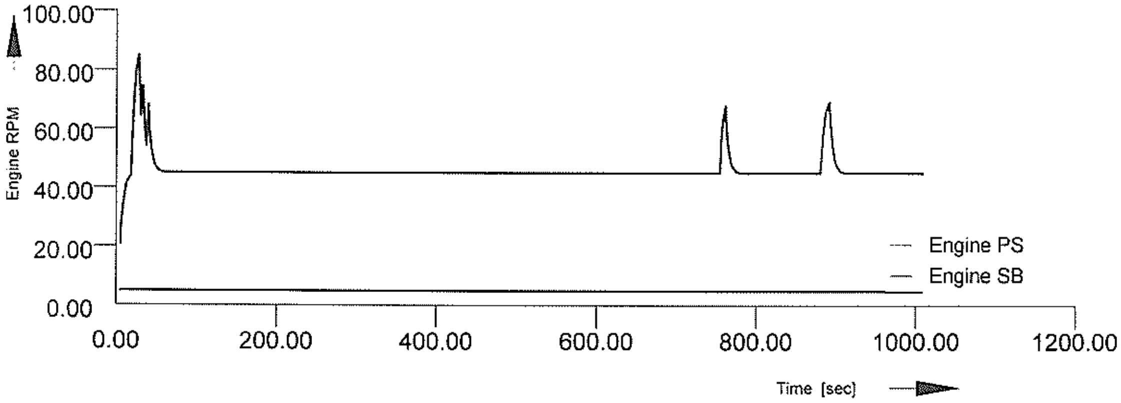


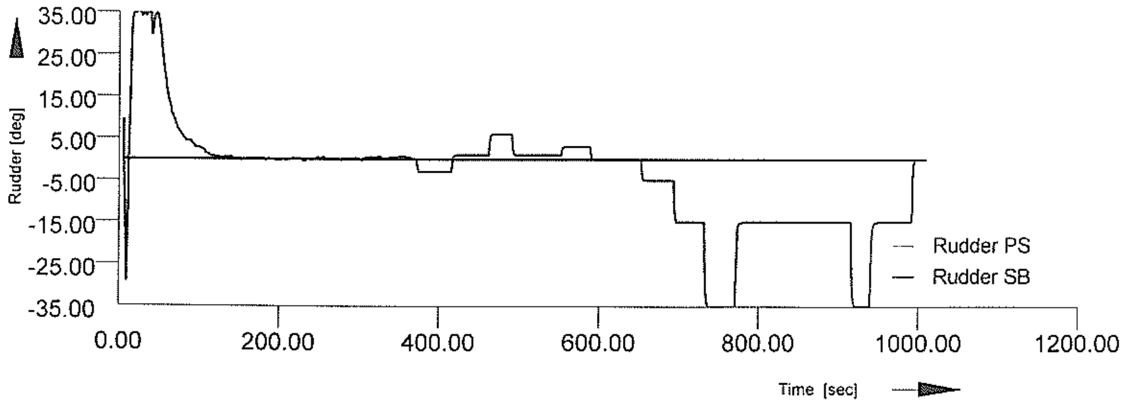
Real time Set I.2a Condition 51	R20 W. Welvaarts June 2001
AVV Transport Research Centre B010	

Alkyon 6/22/01 2.48 28 AM



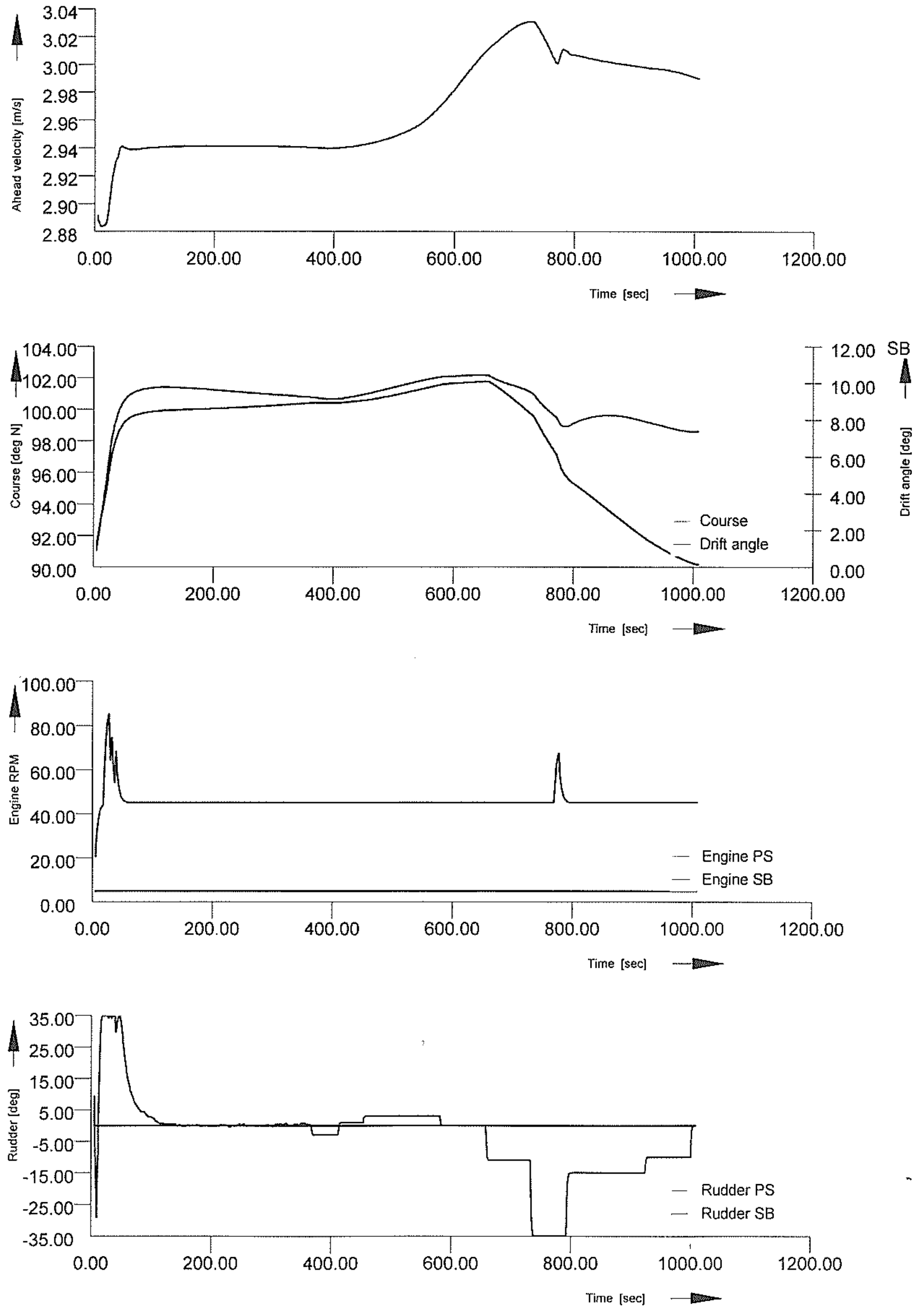






Real time Set I.2a Condition 51	R21	
	W. Welvaarts	
	June 2001	
AVV Transport Research Centre	B010	

Alkyon 6/22/01 2:48:52 AM



Real time Set I.2a Condition 51	R22 W. Welvaarts June 2001
AVV Transport Research Centre B010	