

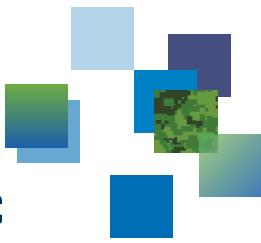


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CFMETR2015 Trial PLAN: Infrared Ship Wakes Signatures Measurement

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Defence Research and Development Canada
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Abstract

In a defense context, wake measurement is a capability that, in addition to being indispensable for our infrared wake modeling validation, allows ship vulnerability assessment and studies that can enhance ship positioning and recognition algorithms. Although, ship wakes are complex dynamic disturbance of the sea surface. Unlike the ships, their total length extends up to many kilometers downstream the ship which makes their infrared signature measurements an even more challenging problem than the infrared measurement of the ship platform itself. Furthermore, the Infrared signature of a ship wakes depends on ship design, configuration and operational parameters, climatic and environmental information, time and geographical position and the receiver characteristics and position. Hence, gathering all resources required for infrared wake measurement trial results in an expensive and logically challenging trial. For each wake component, we have defined the specific measurement requirements. Within the available and affordable resources, we have designed helicopter tracks that allow us to cover, for all wakes sub area, a high and low zenith receiver angles and multiple azimuthal receiver angles. For an optimal use of the helicopter flight time, runs were designed from an ordered sequence of tracks minimizing the helicopter repositioning time, so the start location of each track is the closest location to the end point location of the previous track. Nevertheless, the run design was conceived to have a total sequence length that can be traveled within the fueling capacity of the helicopter and the necessary time for the ship to sail at the required speed and course within the range site limit. This run will be repeated four times per day to cover different sun elevation. An additional run is planned with multiple ship speeds. For the two day trial, we have dedicated one day for infrared MW measurement and the second day for infrared LW measurement.

Résumé

Dans un contexte de la défense, la mesure du sillage de navire est une capacité qui, en plus d'être indispensable pour la validation de la modélisation de la radiance infrarouge du sillage, permet l'évaluation de vulnérabilité et susceptibilité du navire et l'amélioration des algorithmes de détection et reconnaissance de navire. Néanmoins, les sillages de navires est un problème complexe de perturbation dynamique de la surface de l'eau et, contrairement aux navires, leurs longueurs s'étend jusqu'au plusieurs kilomètre ce qui rend la mesure de leurs sillages un défi encore plus difficile que celui de la mesure de la signature de la structure de navire. De plus, la signature infrarouge de sillage de navire dépend de la conception du navire, sa configuration et ses paramètres opérationnels, des informations environnementales et climatiques, du temps, de la date et la position géographique ainsi que de la position et des caractéristiques du récepteur. Ainsi, ressembler tous les ressources nécessaire pour un

essai de mesure de sillage est un défi logistique et couteux à la fois. Pour chaque composante du sillage, nous avons défini les mesures spécifiques nécessaires. Avec les ressources disponibles et abordables, nous avons conçu des passages d'hélicoptère qui permettent de couvrir, pour toutes les composantes des sillages, des grands et petits angles de zénith et plusieurs angles azimut. Pour une utilisation optimale du temps de vol de l'hélicoptère, les trajets ont été conçus à partir d'une séquence ordonnée de passages minimisant le temps de repositionnement de l'hélicoptère, de sorte que l'emplacement de départ de chaque piste est l'endroit le plus proche de l'emplacement final du passage précédente. De plus, les trajets ont été conçus pour avoir une durée totale dans la limite de la capacité de ravitaillement de l'hélicoptère et du temps requis par le navire pour voyager à la vitesse et direction voulue dans les limites du site d'essai. Pour un essai de deux jours, nous avons dédié une journée pour les mesures Infrarouge MW et l'autre jour pour les mesures infrarouge LW. Ce trajet va être répété quatre fois par jour d'essai afin de couvrir des différentes positions du soleil et ainsi des différentes radiances du ciel. Un trajet additionnel a été conçu avec des multiples vitesses de navire.

Acknowledgements

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1 Introduction

In support of the project 01ec, our modeling of the infrared radiance of the ship wakes and the sea background detailed in references [1], [2] and [3] extends to the sea surface background and to the three components of the ship wakes shown in Figure 1. Ship wakes form a distinct disturbance of the background sea surface and their measurement is an important capability for ship wake infrared signature assessment. This last allows ship vulnerability studies that can enhance ship positioning and recognition algorithms.

In this trial, wake measurement is planned to collect data that will be used for modeling validation of the following:

- Turbulent wake modeling:
 - Sea surface roughness variation in the turbulent wake (cross stream and down stream variation).
 - Sea surface temperature variation in the turbulent wake (cross stream and down stream variation).
- Kelvin wake modeling:
 - Modeling of the Kelvin wake pattern for different speed and acceleration.
 - Modeling of the sea surface roughness variation in the Kelvin wake.
- Modeling of the downstream and cross stream white water wake length.

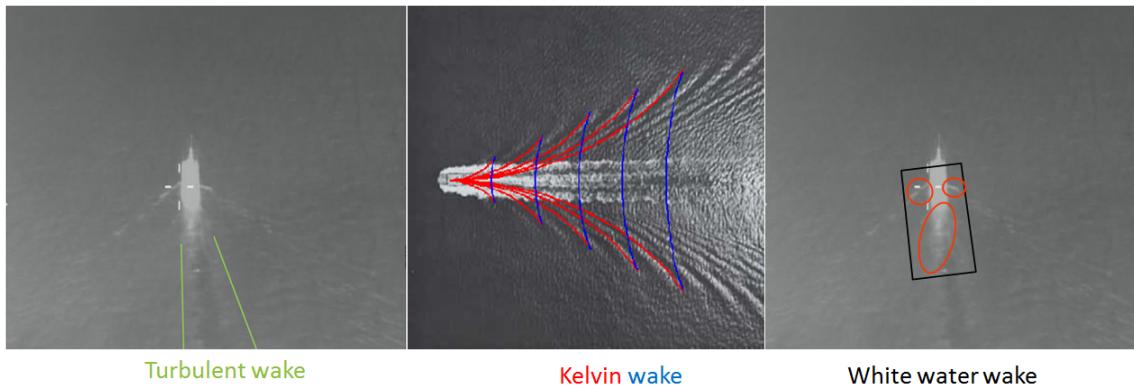


Figure 1: The different components of a ship wake: Turbulent trail, Kelvin waves, and white water zone.

This manuscript is organized as follows: Section 2 and 3 present the objective and classification of the trial; Section 4 present the required equipments, platforms and personnel resources; Section 5 describes the planned experience with way-points, ship tracks, helicopter tracks and the planned runs.

2 Objectives of the trial

The objective of the trial is to collect data required for a first phase validation of the previously enumerated models of our Sea Surface Radiance simulator.

3 Classification

The existence of this trial and the full contents of this trial plan are all UNCLASSIFIED.

4 Requirements

Our measurements require a range facility with naval platform and a helicopter. Instrumentation as infrared sensors, motion sensors, weather station, and sea surface and depth water profiling are required on-board the helicopter and/or the naval platform.

4.1 Range facility

Trial will take place at Canadian Forces Maritime Experimental and Test Ranges (CFMETR) in the Nanoose Bay area of British Columbia the 25th and 26th of August 2015. The range is operating a CFNAV STIKINE Naval Platform and a Bell206L Helicopter. Furthermore, a scientific team from the range is working on the development of a new measurement tool of the sea surface temperature depth inside the ship wake down to 30 ft. depth [4].

Following are the parameters expected to be measured by the range:

- **Sea temperature and stratification:** Data from the thermal array system build by the range team and the expendables buoys (Background and Wake) are required to be collected and saved.
- **Meteorological data onboard the ship:** A meteorological data station is available on-board the ship. The output data should be logged and saved.

- **Ship GPS position:** Ship GPS position is required and will be registered by the range.
- **Helicopter GPS position or relative position to the ship:** Helicopter to ship relative position is required and will be registered by the range.
- **Sea background temperature measurement:** For each run, one expandable bathymetric buoys should be launched near the ship from a CFMETR motor work-boat outside the wake. The range will register the data collected from the buoys.
- **Ship wake temperature measurement:** For each run, thermal measurement of water down to 30 ft. depth will be done by the range team.

4.2 Naval platform

A naval platform is required in order to generate a ship wake. The ship used in this trial is the CFNAV STIKINE. Following are the parameters required to be collected from the ship:

- **GPS position:** The GPS position will be registered by the CFMETR range.
- **The shaft speed** cannot be logged automatically; a manual log of the shaft should be done by the DRDC personnel onboard.
- **Ship motion:** A NAV420CA will be sent from DRDC – Atlantic Research Centre to the Range. This hardware will be installed on the ship by a DRDC personnel and connected to the Laptop S. Once installed, this hardware will be operated by DRDC personnel on board the ship.
- **Meteorological data** onboard the ship: A meteorological data station is available onboard the ship. The output data should be logged and saved.

4.3 Helicopter

A Bell206L will be used to fly the sensors in order to cover the needed receiver positions. Following are the parameters required to be registered from the helicopter:

- **Helicopter GPS position or relative position to the ship:** This data will be given by the range.
- **IR data:** A FLIR SC6000 longwave Infrared and a FLIR SC8303 Middle wave Infrared sensor will be used to collect IR signature of the ship wake. A Taylor Mount (Middle Mount II) will be used to secure and allow the operation of

the IR sensor on board. The IR sensor must be connected to the helicopter electrical power and to the Laptop A.

Two DRDC personnel is required to operate sensors and material onboard the helicopter.

4.4 List of the parameters and measurements units

Information or data required before the trial:

- Ship design and hull documentation
- Meteorological forecast

Table 1 shows the list of data required during the trial and the related instrumentation.

Table 1: List of the required parameters and measurements units.

Parameters	Instrument	Operated by	Data Log
Helicopter			
GPS position	Range GPS	Range	Hard Disk 1
IR data	FLIR SC6000 LW FLIR SC8308 MW Taylor Mount Laptop A	2 DRDC personnel on board Helicopter	Laptop A
Heading	Motion Sensor	2 DRDC personnel on board Helicopter	Laptop A
Ship			
GPS Position	Range GPS	Range	Hard Disk 1
Ship motion	NAV420CA Laptop S	1 DRDC personnel on board ship	Laptop S
Shaft	Visual reading	1 DRDC personnel on board ship	Logbook
Wind speed Air T, RH Bar. Pressure	Visala, Laptop L	1 DRDC personnel on board ship	Laptop L
Background			
Thermal Measurment	Bathymetry and Thermal array Boat	Range	Hard Disk 1

5 Description of experiments

5.1 Waypoints

Table 2 shows the way-points of the trial and Figure 2 shows their positions on the map.

Table 2: Ship waypoints.

Waypoints	Latitude	Longitude
P1	N49°20'10.00"	W123°49'12.00"
P2	N49°20'8.40"	W123°56'33.00"
P3	N49°18'45.50"	W123°56'37.00"
P4	N49°18'43.00"	W123°54'7.00"
P5	N49°18'24.00"	W123°54'9.00"
P6	N49°18'25.00"	W123°51'42.00"
P7	N49°18'6.25"	W123°51'39.40"
P8	N49°18'6.17"	W123°49'8.61"



Figure 2: Ship tracks and waypoints. Source: <http://www.earth.google.com>
29 June, 2013.

5.2 Ship tracks

Table 3 describes the ship tracks for the different runs.

5.3 Helicopter

Four different helicopter tracks will be required: cross-stream the wake, special cross-stream the wake, downstream the wake and in an elliptic trajectory around some

specific area of the wake. Following subsections describe these tracks type.

Table 3: Ship tracks.

leg	start point	toward point	length (km)
L0	P1	P2	9
L1	P3	P4	3
L2	P5	P6	3
L3	P7	P8	3

5.3.1 Top downstream track type (TD)

Here, the helicopter starts from above the ship (zenith, azimuth, height) = (0, 0, height) and follows the downstream direction above the central line of the wake at a fixed height until a specified downstream distance. For a 17mm lenses, the ideal heights should be at 930 m and at 3000 m for respectively 3 km and 9km downstream run distance.

Table 4: Downstream helicopter track.

Track number	height	downstream distance end
TD1	930	3 km

5.3.2 Cross-stream track type (CS)

Here, the helicopter starts from a specified position relative to the ship ($x, y, height$) and moves cross stream perpendicular to the ship track at a constant height until arriving to a specified end point. In this track, the x and z helicopter relative coordinates to the ship are constants.

Table 5: Cross-stream helicopter track.

Track number	start position ($x, y, height$)	End position
CS1	(400 m, -10 km, 1000 m)	(400 m, 1000 m, 1000 m)

5.3.3 Special cross-stream track type for zenith measurement with fixed azimuth and range (SCS)

Instead of a simple cross stream perpendicular to the wake at a fixed height x, in the special cross-stream runs the helicopter modifies its height to cover all zenith angles for a fixed radius and azimuth relative to a predetermined trajectory center

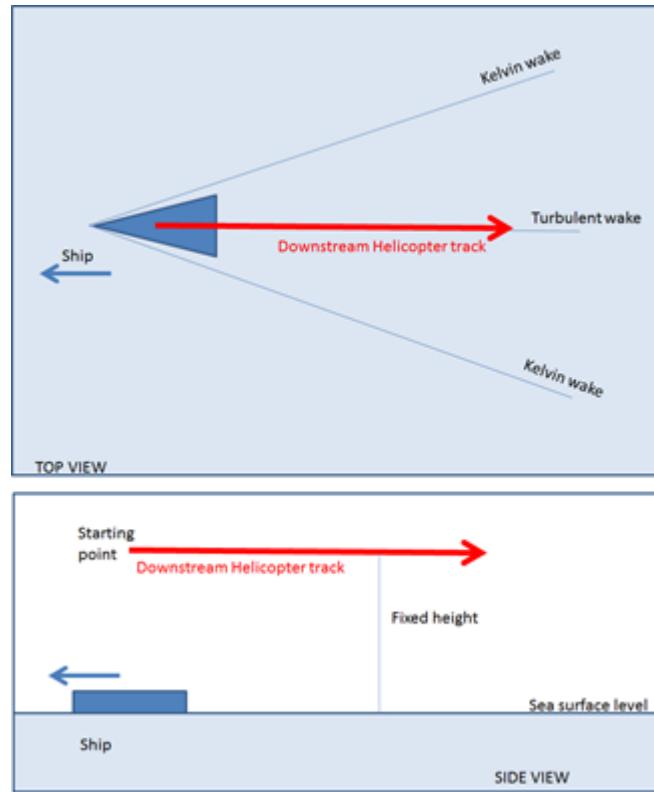


Figure 3: Downstream helicopter track.

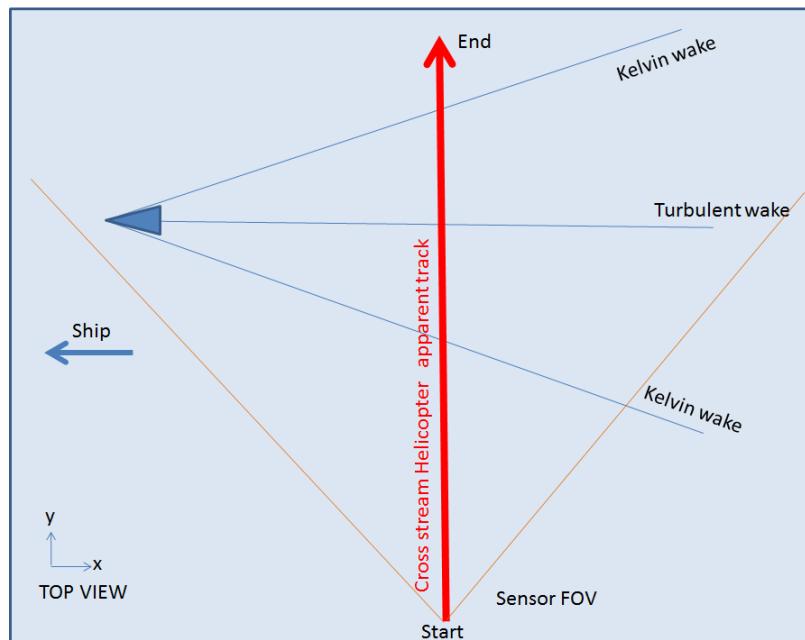


Figure 4: Cross-stream helicopter track.

(TC). We identify these runs by the trajectory center relative coordinate to the ship and the radius of the trajectory. The start and end point depends on the helicopter lower possible height on the sea surface. Table 8 shows the two needed cross-stream helicopter tracks and Table 7 shows the helicopter relative coordinates to the ship for the first track (x_1, y, z) and in the second track (x_2, y, z). The coordinates are provided for the half of each tracks as the track is symmetrical.

Table 6: Special cross-stream helicopter track.

Track	Trajectory center	Fixed trajectory radius
SCS1	0,0,0	1000m
SCS2	400,0,0	1000m

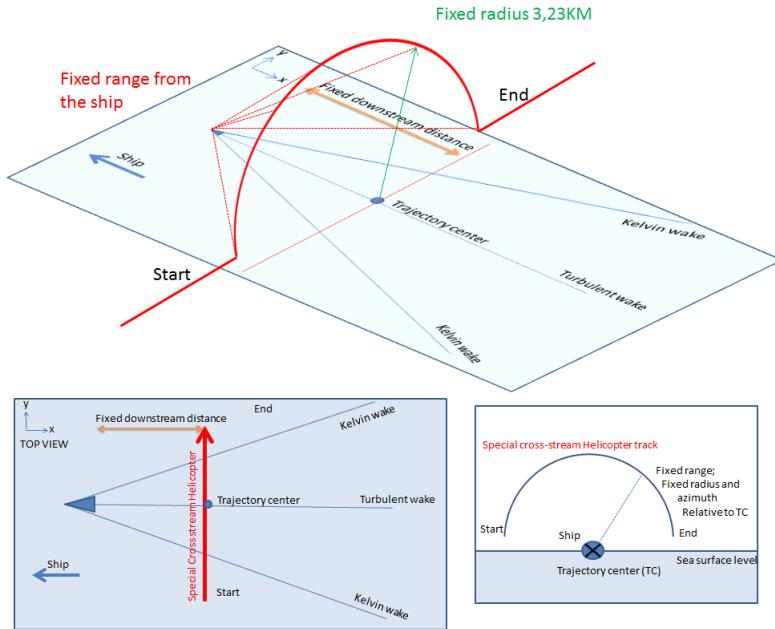


Figure 5: Special cross-stream helicopter track.

5.3.4 Elliptical track type (E)

The helicopter starts from a specified position relative to the ship (zenith, azimuth, height) and moves in a circular shape track relative to a specified fixed point relative to the ship. These tracks have are identified by the height, the zenith angle and the center. Table 8 shows the elliptical tracks start positions, fixed zenith and fixed height.

Table 7: Helicopter relative coordinates to the ship in the first track ((x_1, y, z)) and in the second track ((x_2, y, z)).

x1	x2	y	z
0	400	3218	87
0	400	3181	174
0	400	3120	259
0	400	3035	342
0	400	2927	423
0	400	2797	500
0	400	2646	574
0	400	2474	643
0	400	2284	707
0	400	2076	766
0	400	1852	819
0	400	1615	866
0	400	1365	906
0	400	1105	940
0	400	836	966
0	400	561	965
0	400	282	985
0	400	0	996

Table 8: Elliptical tracks.

Track number	Start positions (x, y, z) (m)	Centre of the apparent circle (x, y, z) (m)	Fixed height (m)	Radius
E1	(400, 1000, 1000)	(200, 0, 1000)	1000	1000

5.3.5 Side downstream track type (SD)

The helicopter starts from a determined position relative to the ship (x, y, z) and follows the downstream direction above the central line of the wake at a fixed height until the specified downstream distance.

Table 9: Downstream helicopter track.

Track number	Height	Downstream distance end	Side distance	Speed
SD1	930	3 km	340 m	fixed

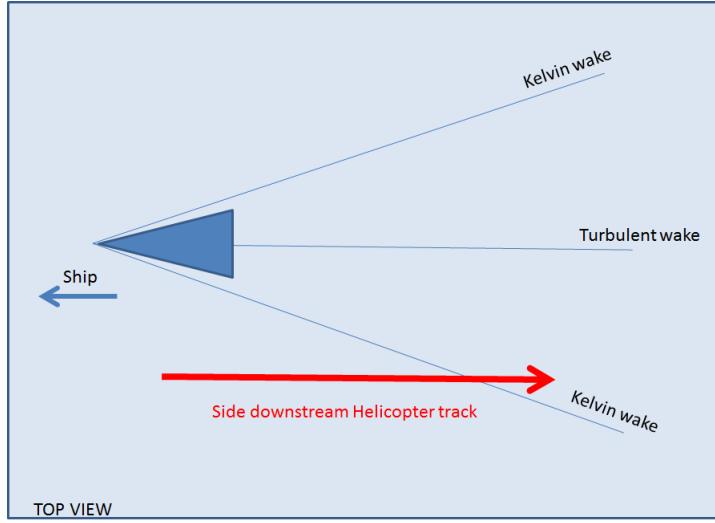


Figure 6: Side downstream helicopter track.

5.4 Runs

The two following subsections shows the different runs for the two days trial. All the runs except run3 and run8 has the same helicopter tracks sequence. Figure 7 shows the total tracks sequence.

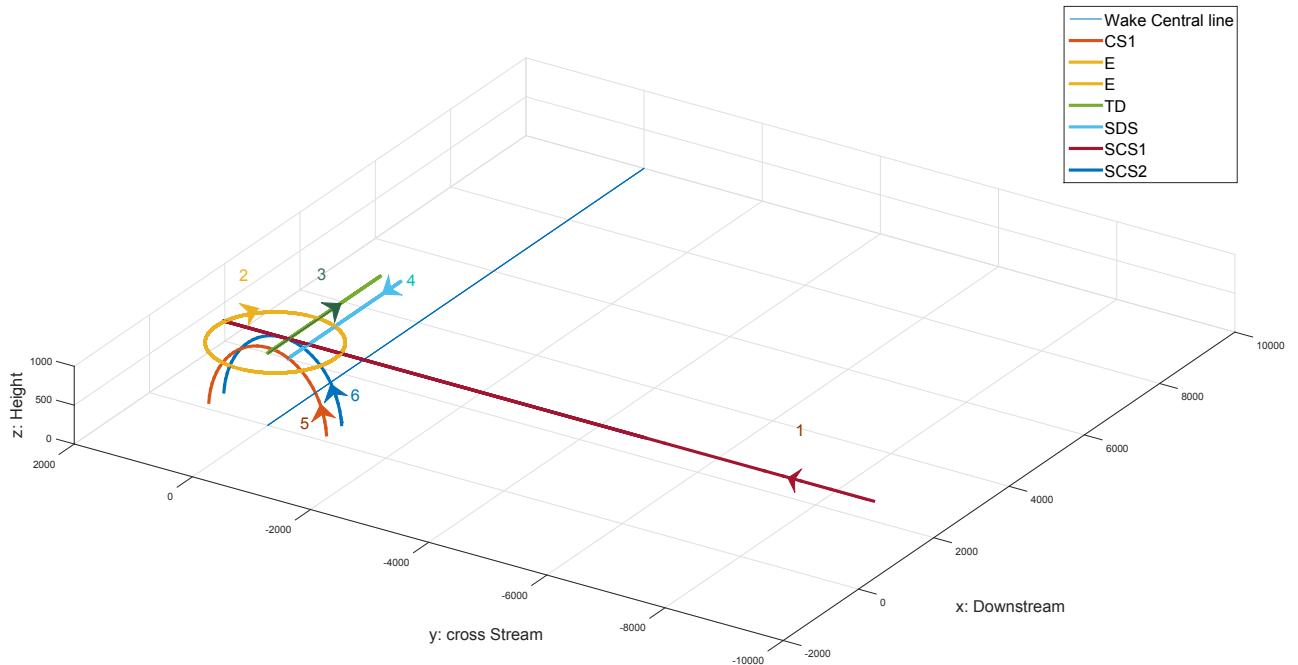


Figure 7: The total tracks type of the helicopter.

5.4.1 Day 1

Tables 10, 11, 12, 13 and 14 show the first day runs. All runs are measured with MW Infrared camera with 17 mm lenses.

Table 10: Run 1.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
25 Aug 2015	800	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1, SCS2

Table 11: Run 2.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
25 Aug 2015	1000	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1 or SCS2

Table 12: Run 3.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
25 Aug 2015	1200	L1	full speed (FS)	yes	TD1, SD1
25 Aug 2015		L2	12	yes	TD1, SD1
25 Aug 2015		L3	8	yes	TD1, SD1

Table 13: Run 4.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
25Aug 2015	1400	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1 or SCS2

Table 14: Run 5.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
25 Aug 2015	1600	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1 or SCS2

5.4.2 Day 2

Tables 15 to 19 show the second day runs. All runs are measured with LW Infrared camera with 17 mm lenses.

Table 15: Run 6.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
26 Aug 2015	800	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1 or SCS2

Table 16: Run 7.

D2	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
26 Aug 2015	1000	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1 or SCS2

Table 17: Run 8.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
26 Aug 2015	1200	L1	full speed (FS)	yes	TD1, SD1
26 Aug 2015		L2	12	yes	TD1, SD1
26 Aug 2015		L3	8	yes	TD1, SD1

Table 18: Run 9.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
26 Aug 2015	1400	L0	full speed (FS)	yes	
	After 3 km of full ship speed	L0	full speed (FS)		CS1, E1, TD1, SD1, SCS1 or SCS2

Table 19: Run 10.

Date	Time	Ship track	Ship Speed [knt]	Buoys Deployment	Helicopter track
26 Aug 2015	1600	L0	10	yes	
	After 3 km of full ship speed				CS1, E1, TD1, SD1, SCS1 or SCS2

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- [2] V. Issa and Z. A. Daya, "Sea Surface Infrared Radiance Simulator Part 2: Sky Radiance and Trailing wake Integration models of the Sea Surface Radiance, DRDC Atlantic TM 2011-325, Defence R&D Canada - Atlantic," (2010).
- [3] V. Issa and Z. Daya, "Modeling the turbulent trailing ship wake in the infrared," *Applied Optics* **53**, 4282–4296 (2014).
- [4] T. Hix, "ME 1523 Wake Characterization Trial 25 Jun 15 Thermal Measurements," CFMETR POAS p. 14 (2015).

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Ship wake; white water wake; turbulent wake; Kelvin wake

13. ABSTRACT/RÉSUMÉ (When available in the document, the French version of the abstract must be included here.)

In a defense context, wake measurement is a capability that, in addition to being indispensable for our infrared wake modeling validation, allows ship vulnerability assessment and studies that can enhance ship positioning and recognition algorithms. Although, ship wakes are complex dynamic disturbance of the sea surface. Unlike the ships, their total length extends up to many kilometers downstream the ship which makes their infrared signature measurements an even more challenging problem than the infrared measurement of the ship platform itself. Furthermore, the Infrared signature of a ship wakes depends on ship design, configuration and operational parameters, climatic and environmental information, time and geographical position and the receiver characteristics and position. Hence, gathering all resources required for infrared wake measurement trial results in an expensive and logistically challenging trial. For each wake component, we have defined the specific measurement requirements. Within the available and affordable resources, we have designed helicopter tracks that allow us to cover, for all wakes sub area, a high and low zenith receiver angles and multiple azimuthal receiver angles. For an optimal use of the helicopter flight time, runs were designed from an ordered sequence of tracks minimizing the helicopter repositioning time, so the start location of each track is the closest location to the end point location of the previous track. Nevertheless, the run design was conceived to have a total sequence length that can be traveled within the fueling capacity of the helicopter and the necessary time for the ship to sail at the required speed and course within the range site limit. This run will be repeated four times per day to cover different sun elevation. An additional run is planned with multiple ship speeds. For the two day trial, we have dedicated one day for infrared MW measurement and the second day for infrared LW measurement.

Dans un contexte de la défense, la mesure du sillage de navire est une capacité qui, en plus d'être indispensable pour la validation de la modélisation de la radiance infrarouge du sillage, permet l'évaluation de vulnérabilité et susceptibilité du navire et l'amélioration des algorithmes de détection et reconnaissance de navire. Néanmoins, les sillages de navires est un problème complexe de perturbation dynamique de la surface de l'eau et, contrairement aux navires, leurs longueurs s'étendent jusqu'au plusieurs kilomètre ce qui rend la mesure de leurs sillages un défi encore plus difficile que celui de la mesure de la signature de la structure de navire. De plus, la signature infrarouge de sillage de navire dépend de la conception du navire, sa configuration et ses paramètres opérationnels, des informations environnementales et climatiques, du temps, de la date et la position géographique ainsi que de la position et des caractéristiques du récepteur. Ainsi, rassembler tous les ressources nécessaire pour un essai de mesure de sillage est un défi logistique et couteux à la fois. Pour chaque composante du sillage, nous avons défini les mesures spécifiques nécessaires. Avec les ressources disponibles et abordables, nous avons conçu des passages

d'hélicoptère qui permettent de couvrir, pour toutes les composantes des sillages, des grands et petits angles de zénith et plusieurs angles azimut. Pour une utilisation optimale du temps de vol de l'hélicoptère, les trajets ont été conçus à partir d'une séquence ordonnée de passages minimisant le temps de repositionnement de l'hélicoptère, de sorte que l'emplacement de départ de chaque piste est l'endroit le plus proche de l'emplacement final du passage précédente. De plus, les trajets ont été conçus pour avoir une durée totale dans la limite de la capacité de ravitaillement de l'hélicoptère et du temps requis par le navire pour voyager à la vitesse et direction voulue dans les limites du site d'essai. Pour un essai de deux jours, nous avons dédié une journée pour les mesures Infrarouge MW et l'autre jour pour les mesures infrarouge LW. Ce trajet va être répété quatre fois par jour d'essai afin de couvrir des différentes positions du soleil et ainsi des différentes radiances du ciel. Un trajet additionnel a été conçu avec des multiples vitesses de navire.