ONR Tumblehome Free-running Test Data for CFD Workshop Tokyo 2015

NOMENCLATURE

Fr	Nominal Froude number
H/l	Wave steepness
K_P	Proportional gain for PID rudder control (= 1)
K_I	Integral gain for PID rudder control (= 0)
K_D	Derivative gain for PID rudder control (= 0)
L [m]	Ship length
n [rpm]	Propeller revolution
r [rad/s]	Yaw rate ($r = d\psi/dt$)
t [s]	Time
U [m/s]	Ship speed ($U = \sqrt{u^2 + v^2}$)
u [m/s]	Surge velocity
v [m/s]	Sway velocity
z [m]	Heave
β [deg]	Drift angle ($\beta = -\arcsin(v/U)$)
$\Delta\psi$ [deg]	Yaw angle deviation from desired course ($\Delta\psi = \psi - \psi_C$)
δ [deg]	Rudder angle
ζ [mm]	Measured wave height
ϕ [deg]	Roll angle
λ/L	Wavelength to ship length ratio
θ [deg]	Pitch angle
χ [deg]	Wave encounter angle
ψ [deg]	Yaw angle
ψ_C [deg]	Desired course

Table 1: Principle particulars of the ONR Tumblehome.

	Model Scale
Length (L)*	3.147 m
Breadth	0.384 m
Depth	0.266 m
Draft	0.112 m
Displacement	72.6 kg
Metacentric height	0.0422 m
Natural roll period	1.665 s
Rudder area	0.012 m^2 ´ 2
Block coefficient	0.535
Radius of gyration in pitch	0.246 ´ L
Maximum rudder Angle	±35°

*Length based on Lwl (length waterline)

Table 2: Test conditions for the ONRT.

	Test	Fr	Propeller revolution [rpm]	δ [deg]	y_C[deg]	H/ λ	λ/L	Numbers of runs
Calm water	Course keeping*	0.2	538	N/A	0	0.02		3
Head Wave					0		1.0	3
Following waves					180			3
Beam wave					-90			3
Oblique head wave					-45			3
Quartering wave					-135			3

*Rudder angle controlled by PID controller ($\delta(t) = K_P(y - y_C)$, $K_P = 1.0$, $K_I = K_D = 0$)

Rudder speed: 35.0 [deg/s]

Propeller Acceleration: 300 [rpm/s]

Wavemaker ramp-up time (Time to develop full amplitude): 3.0 [s]

Distance from carriage origin to wavemaker front surface: 34.5[m]

Average water temperature: 18 [°C]

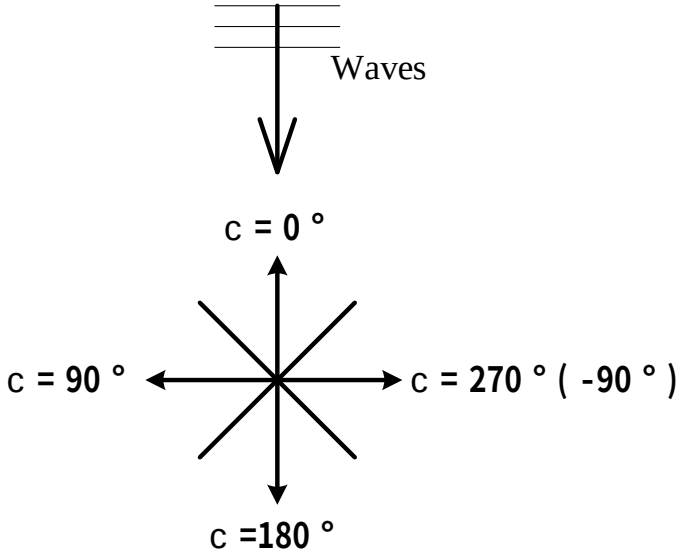

Figure 1: Relationship between ship heading and wave encounter angle.

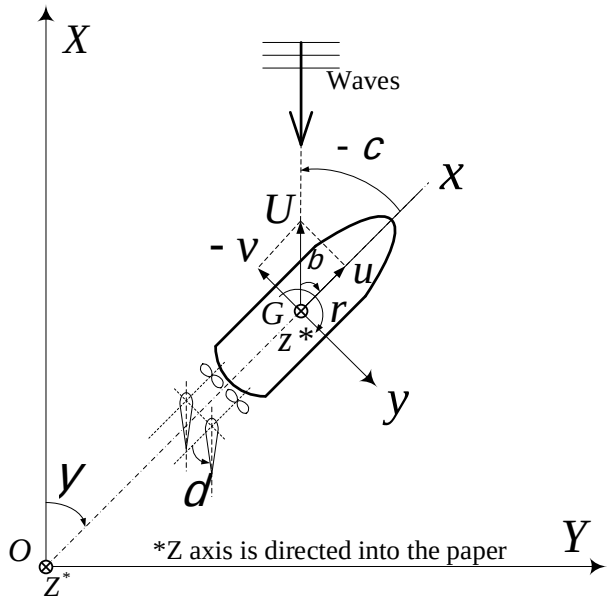

Figure 2: Global coordinate system and ship model fixed coordinate system.

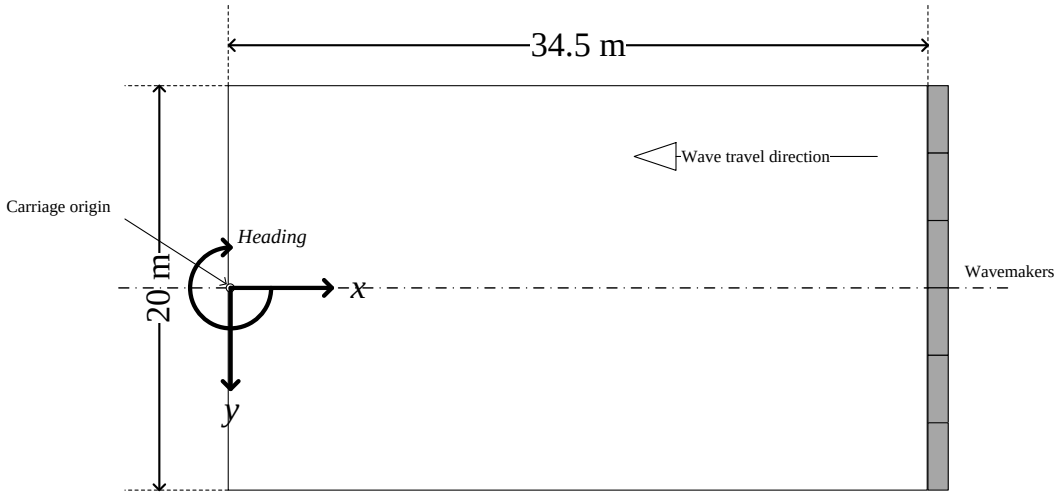

Figure 3: Definition of global coordinate system.

Table 3: Initial Conditions.

Date	Data Serial No.	λ/L	H/λ	Fr	y_C[deg]	Towing Speed [m/s]	Propeller start time [s]	Towing carriage start time [s]	Time to full towing speed [s]	Time to release the model [s]	Initial Position (X [m],Y[m], y [deg])
7/15/2013	HWT521	-		0.2	0	1.11	0	0	1.5	2.5	(0.0,0.0, 0)
7/15/2013	HWT522										
7/15/2013	HWT523										
7/8/2013	HWT469	1.0	0.02		0		30	35	36.5	37.5	(0.0,0.0, 0)
7/15/2013	HWT524										
7/15/2013	HWT525										
7/19/2013	HWT567				-45		30	35	36.5	37.8	(9.0,7.5,-45)
7/19/2013	HWT568										
7/19/2013	HWT570										
7/22/2013	HWT583				-90		30	35	36.5	37.0	(17.0,7.5,-90)
7/22/2013	HWT584										
7/23/2013	HWT585										
7/24/2013	FWT579				-135		30	35	36.5	38.1	(24.0,7.5,-135)
7/24/2013	FWT580										
7/24/2013	FWT581										
7/3/2013	FWT508				180		30	20	21.5	23.5	(29.8,0.0,180)
7/3/2013	FWT509										
7/3/2013	FWT511										

*Time origin is the time to start wavemaker (i.e. t = 0 is the time to start wavemaker).

**The ultrasound wave gauge was installed beside the FP. Actual position is about 100 mm right from the center line until releasing the model. The model was released when the measured wave (z) at the bow is a crest.

Table 4: Definition of status numbers in free-running tests

Status No.*	Status	
	In calm water (Carriage operation starts from t = 0)	In waves (Wavemaker operation starts from t = 0)
1	Captive (Ship is towed by carriage)	Captive and waiting (Both carriage and ship are stopped)
2	Released (Ship starts free-running)	Captive (Ship is towed by carriage)
3	-	Released (Ship starts free-running)

*Status numbers are shown as pink line with measured wave height z from Figures 1-1 to 2-5.

1. TRAJECTORIES AND TIME HISTORIES RESULTS OF COURSE KEEPING TESTS OF ONRT IN CALM WATER

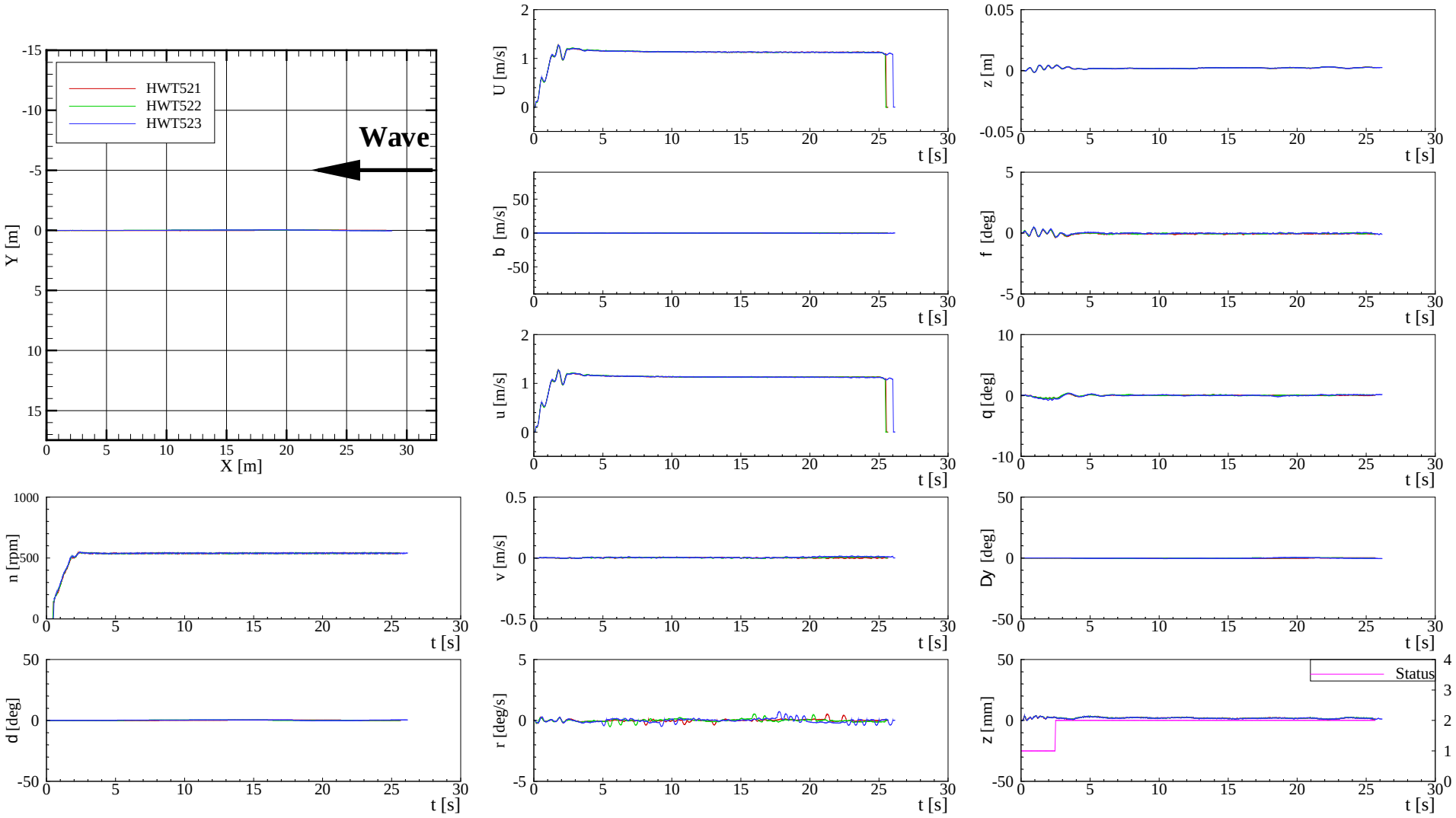

Figure 1-1 Trajectories and time histories of course keeping in calm water at Fr = 0.2 and heading angle = 0°

2. TRAJECTORIES AND TIME HISTORIES RESULTS OF COURSE KEEPING TESTS OF ONRT IN WAVES

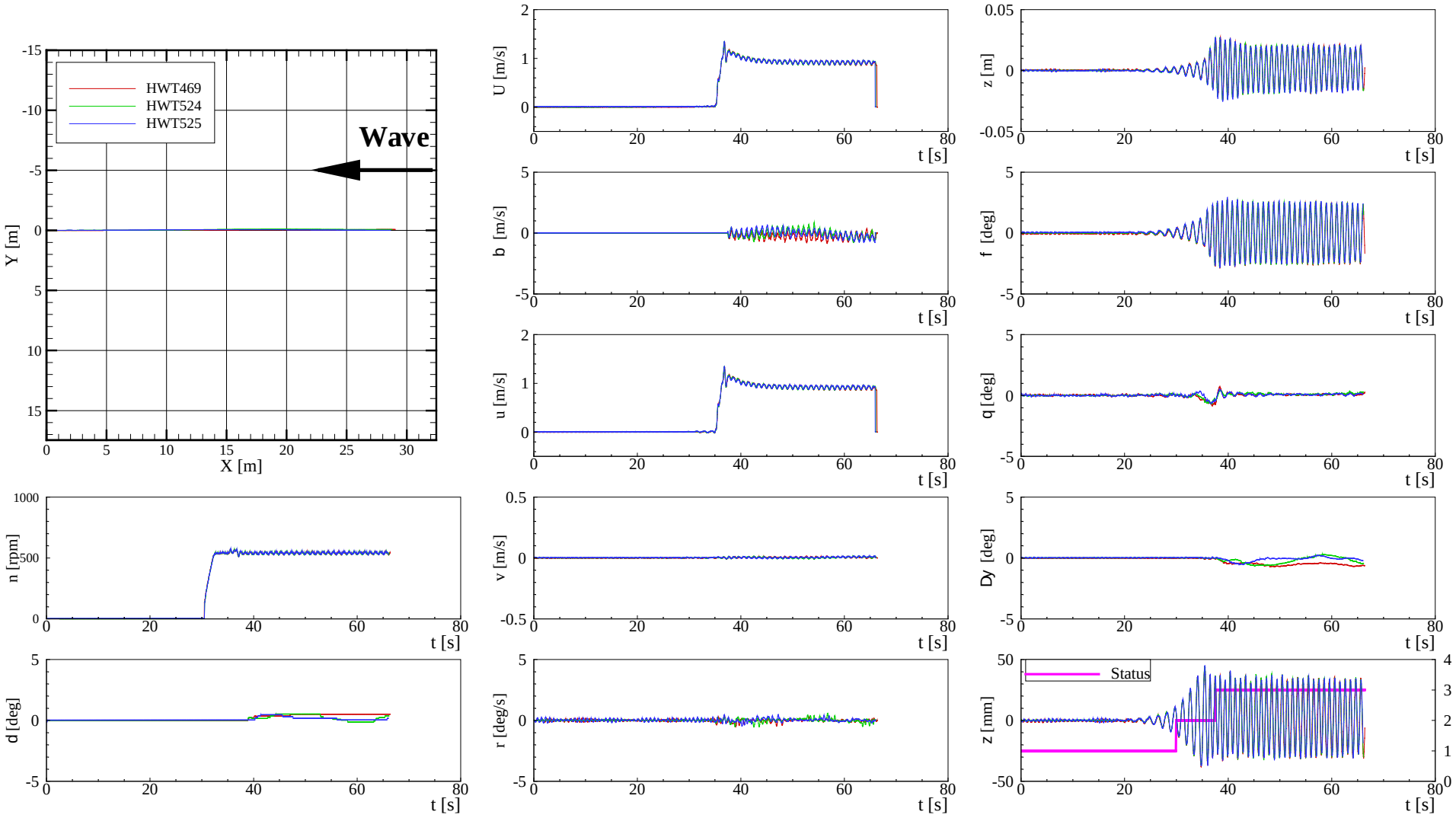

Figure 2-1 Trajectories and time histories of course keeping at Fr = 0.2, λ/L = 1.0, H/λ = 0.02, and heading angle = 0°

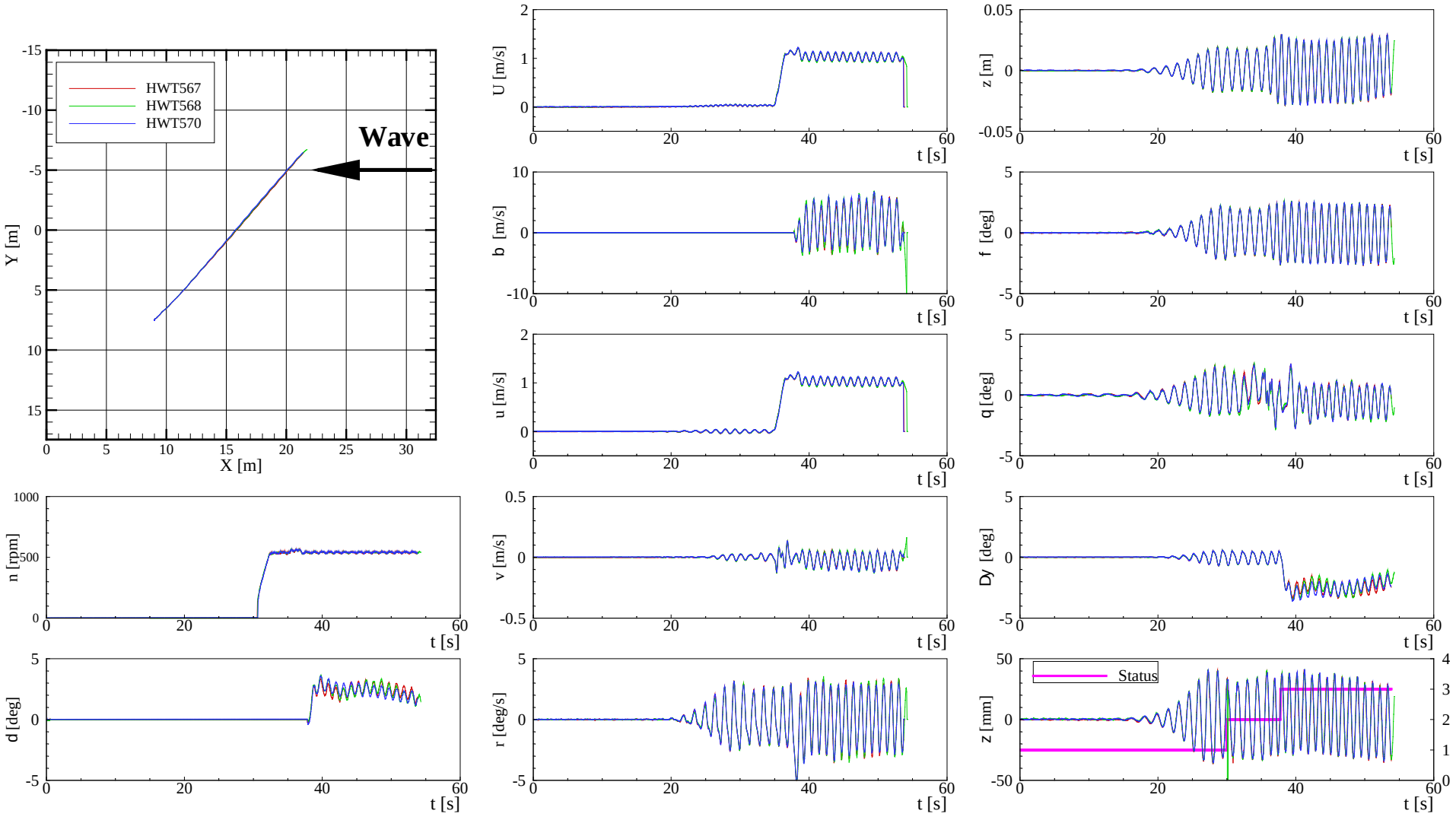

Figure 2-2 Trajectories and time histories of course keeping at Fr = 0.2, λ/L = 1.0, H/λ = 0.02, and heading angle = 45°

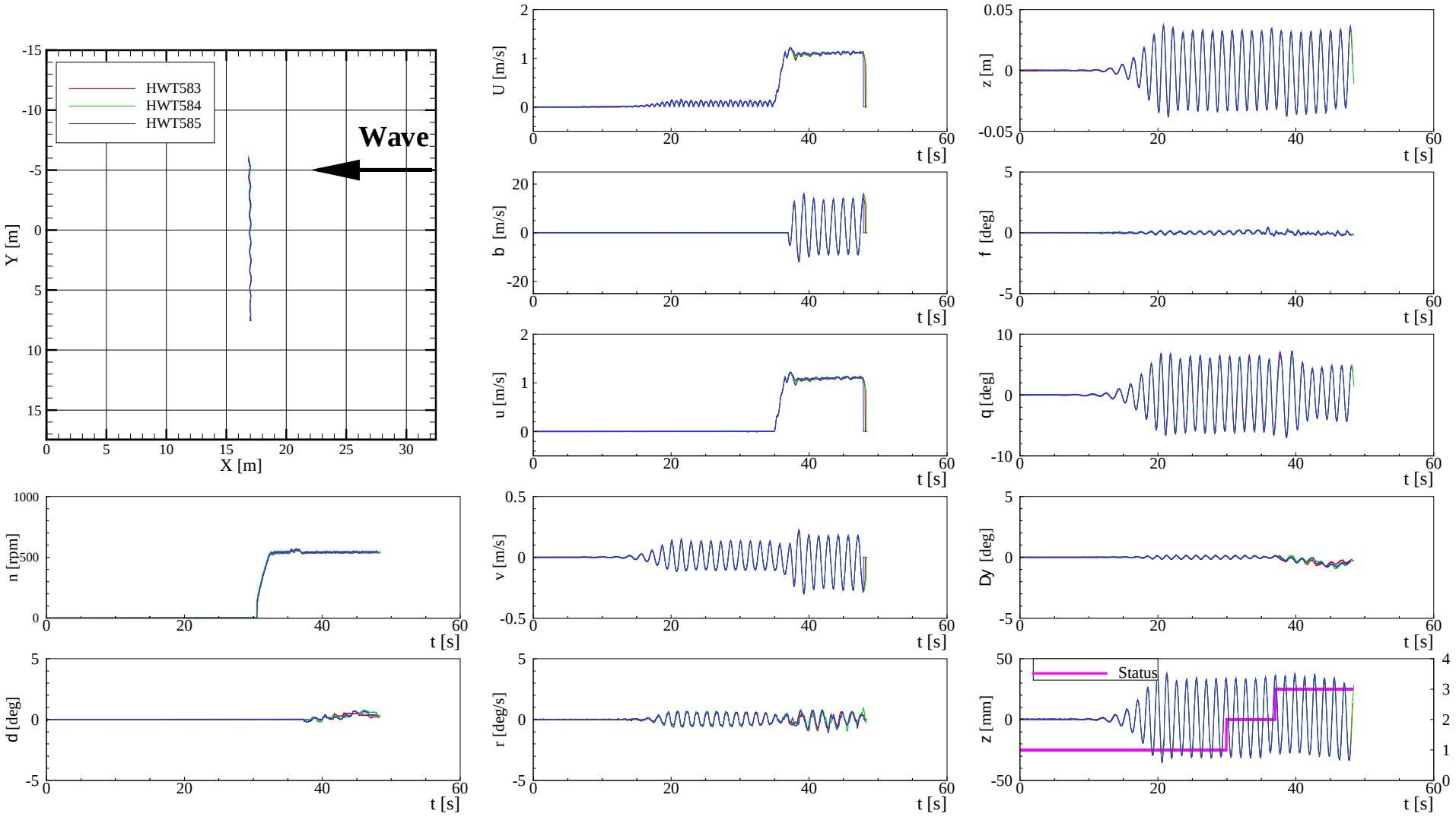

Figure 2-3 Trajectories and time histories of course keeping at Fr = 0.2, λ/L = 1.0, H/λ = 0.02, and heading angle = 90°

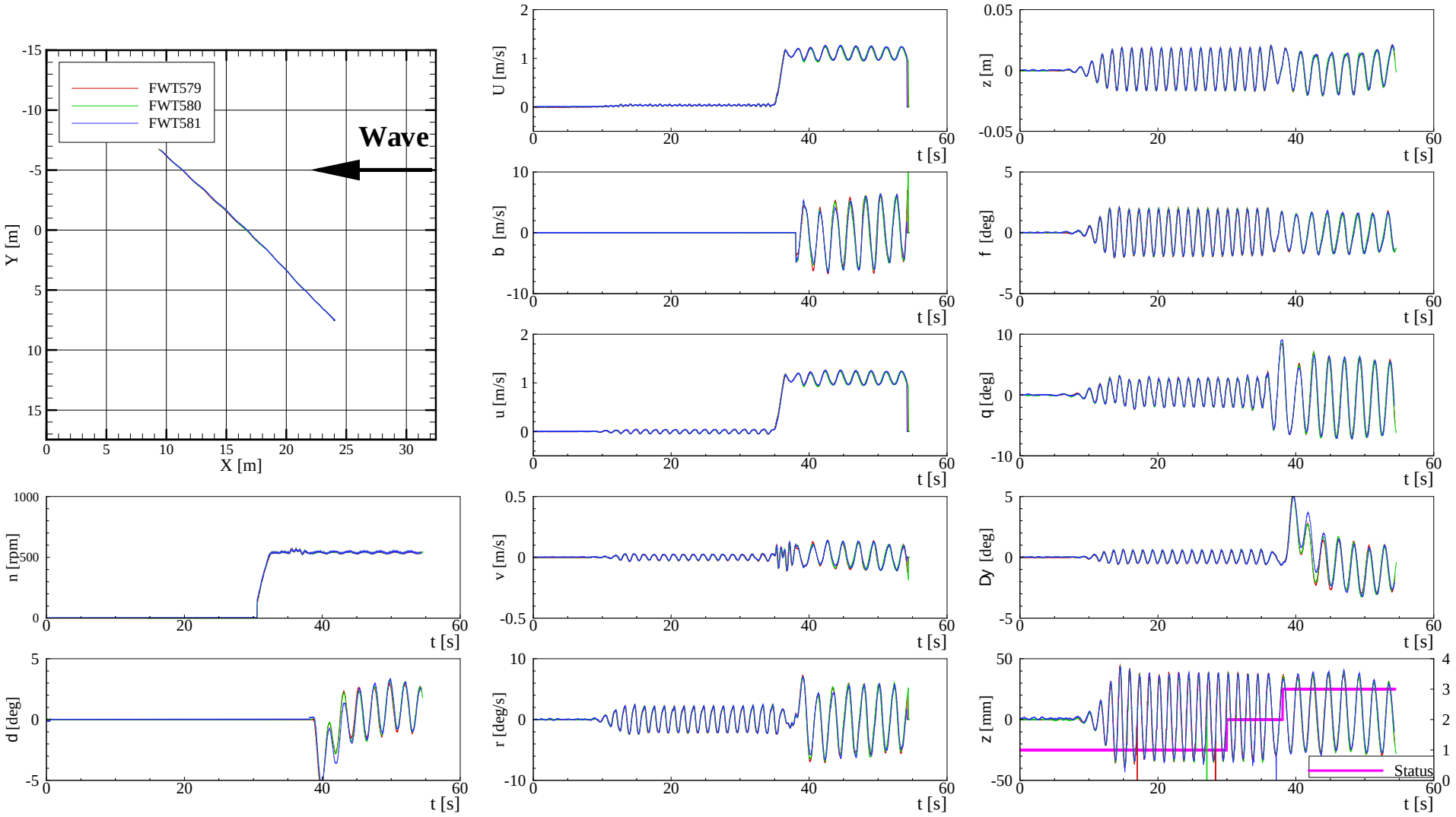

Figure 2-4 Trajectories and time histories of course keeping at Fr = 0.2, λ/L = 1.0, H/λ = 0.02, and heading angle = 135°

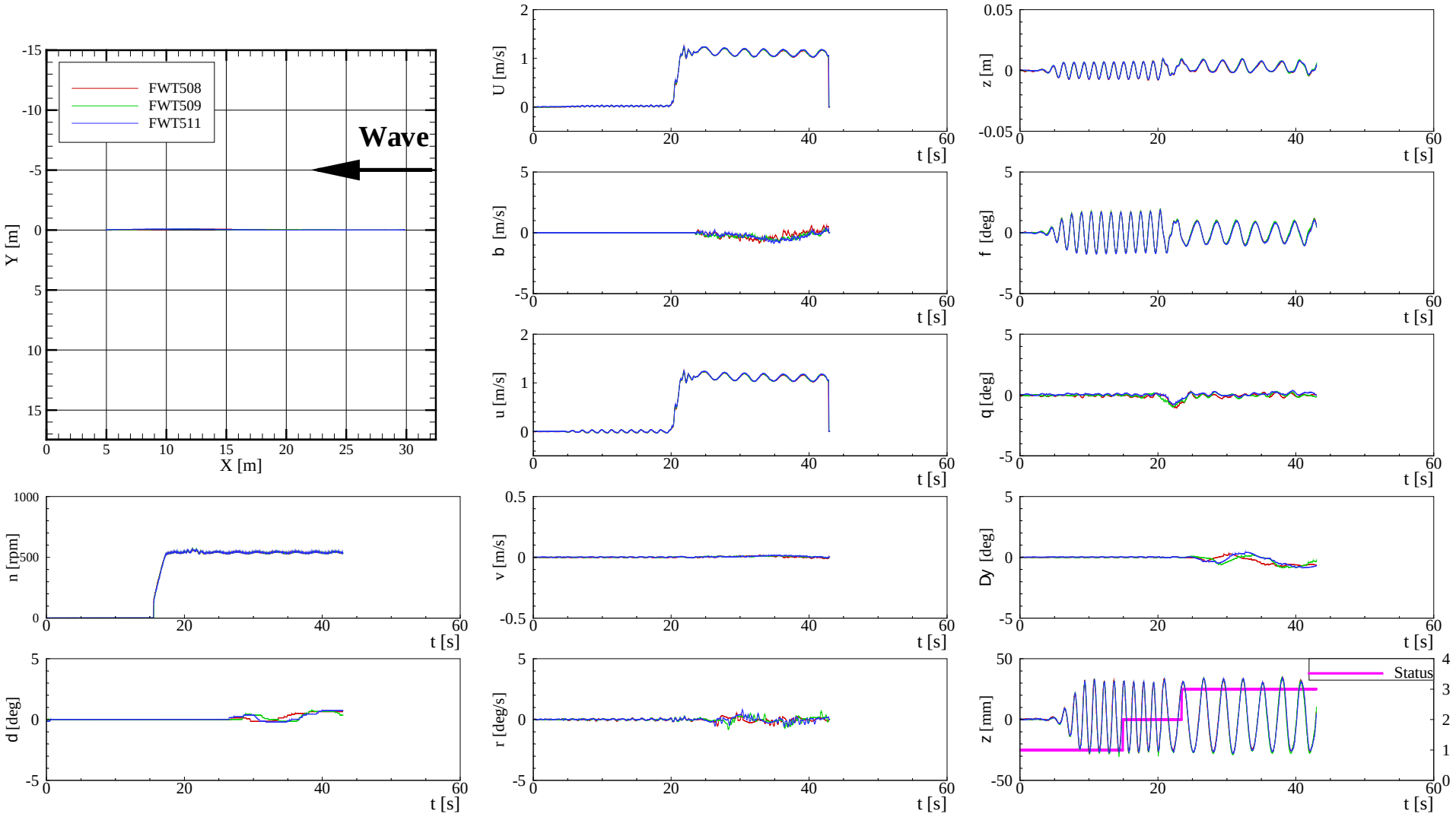

Figure 2-5 Trajectories and time histories of course keeping at Fr = 0.2, λ/L = 1.0, H/λ = 0.02, and heading angle = 180°

References

Sanada, Y., Tanimoto, K., Takagi, K., Toda,Y., Stern, F., “Trajectories and Local Flow Field Measurements around ONR Tumblehome in Maneuvering Motion,” Ocean Engineering, Vol. 72, 2013, pp. 45-65

Sanada, Y., Elshiekh, H., Toda, Y., Stern, F.,“Effects of waves on course keeping and maneuvering for surface combatant ONR Tumblehome,” 2013b, 30th Symposium on Naval Hydrodynamics Hobart, Tasmania, Australia, 2-7 November 2014.

Elshiekh, H., “Maneuvering Characteristics in Calm Water & Regular Waves for ONR Tumblehome,” M.S. The University of Iowa, 2014