Model Experiment of a Launcher of a Deep-Sea Monitoring Robot System

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***Abstract* - National Maritime Research Institute (NMRI), in cooperation with Underwater Technology Research Center, Institute of Industrial Science, University of Tokyo, is developing a Compact Deep-Sea Monitoring Robot System for investigation of sunken ships in deep sea. This system is consisted of a launcher and a small vehicle, and it has characteristics of both AUV and ROV. A launcher corresponds with its mother ship by using optical fiber cable. There is no umbilical cable between a launcher and a vehicle, and the communication is performed by acoustic communication. A launcher submerges holding a vehicle by gravity. It controls its rudders for approaching to a target point. Just before reach the sea bottom, a launcher releases an anchor, launches a vehicle to start mission. In order to pursue the best configuration for effective horizontal movement during descending motion, preliminary calculation and experiments were carried out for two types of configurations, a fuselage with fins and rudders and a fuselage with rudders but no fins. This paper describes the results of calculation and experiments at a deep-sea model basin. The basic mechanism of descend were confirmed.**

I. INTRODUCTION

Though there have been many underwater systems for observation, almost all systems were not compact, and they could not be used easily in an accident. When a ship sank under the sea, the cause of accident and the emergency precautions have to be investigated as soon as possible. So we propose a new compact system for underwater observation. The feature of our system has to be easy portable, to rapidly land on the target and to transmit moving images of target condition to a support vessel by the high-speed data link. We are developing a compact deep-sea monitoring robot system with Underwater Technology Research Center, Institute of Industrial Science, University of Tokyo. This system is consisted of a launcher and a small vehicle, and has the kind of mission scenarios that is shown in Fig.1. A launcher can correspond with its support vessel by using optical fiber cable. A launcher with a small vehicle descends to sea bottom at about 3000m by gravity. It controls its rudders for approaching to a target point. Just before reach the sea bottom, a launcher releases an anchor, launches a small vehicle to start its mission. The small vehicle is controlled remotely through moving image acoustic data link by an operator on the support vessel, and moves autonomy for link cutoff. After the mission,

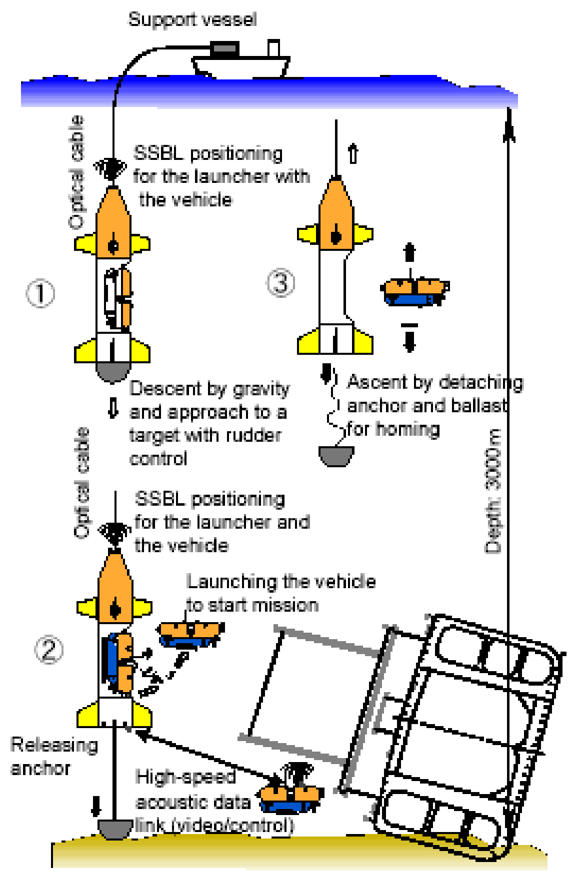

Fig. 1 Mission Scenario of a Deep-sea Monitoring Robot System

each launch and small vehicle detaches anchor and ballast, and ascends by buoyancy.

We planed to study with dividing three important element researches in order to realize this scenario. One research is the designing of launcher. We made a model of launcher, and made experiments to propose the optimum shape. This paper shows mainly the results of this research. Second research is the developing high-speed acoustic data link[2][3]. Last research is the developing a small vehicle of a new type. The feature of this vehicle is that the operator on the mother ship can control it smoothly by using the acoustic link, and that it navigates autonomously in case of AUV mode. During the study duration, we produced the prototype. Though the maximum depth of the prototype is 300m, it equals to the full scale and can perform the mission.

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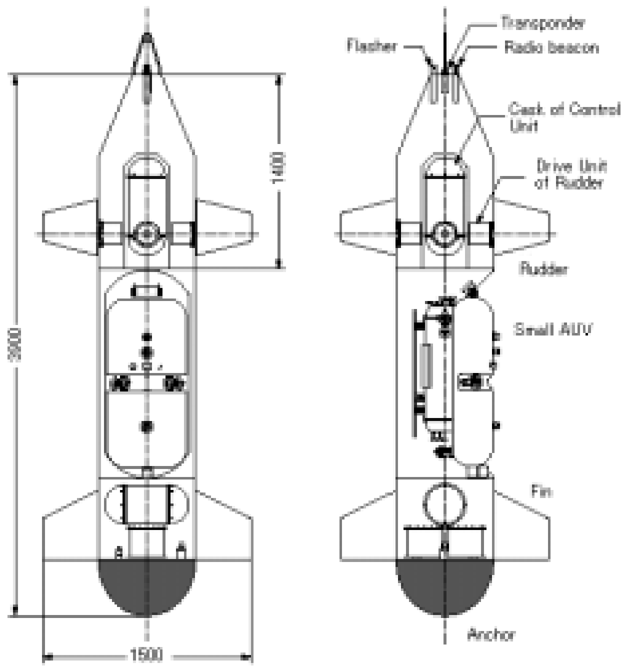
II. LAUNCHER CONCEPT

We think that the launcher design is one of the important factors in order to realize the above-mentioned mission. The launcher is necessary to have functions as follows; it can be carried by an ordinary ship, mount on the small vehicle,



approach rapidly near the target point by gravity, keep to height of 300m over target, launch the small vehicle, communicate to vehicle by high-speed acoustic data link, relay the data to support ship by a optical fiber cable, and ascend to a water surface by a operator's signal. We take account of these functions, we make a concept of the launcher as shown in Fig.2. The releasable anchor is arranged at the tip of the launcher. The vehicle is housed in the middle of fuselage, and the control and battery units are arranged in the space at both sides. When the launcher arrives at about 300m higher position of the target point, the anchor is released and lands the sea bottom. The anchor is cut off after the mission end by the indication of the operator, and the launcher surfaces. So we can focus our attention on the arrangement of fin and rudder. We call the wings of the forepart ‘fin’, and wings of the back part ‘rudder’. Original design[4][5] concept of fin and rudder configuration is as follows. Rudder angle induces incline moment to the launcher. Inclination angle of the launcher induces inflow angle of water into fins. Then fins produce large horizontal force and the launcher can move horizontally. Based on this concept, we decided the principal dimension of the launcher as shown in table 1. Before the model experiment, the linear and nonlinear hydrodynamic calculation was carried out in order to confirm the effectiveness of this design. It was proven that the horizontal movement opposite against intention had been generated in some instance by the calculation. In some cases, it does not move horizontally or moves opposite against intention, though the rudder is controlled for intending horizontal movement. This phenomenon is surmised as effect of large restoring moment against inclination angle due to distance between center of buoyancy and center of gravity. The inclination angle of the launcher becomes small due to the restoring moment. It is not enough to induce inflow angle of water into fins. So the fins do not produce large horizontal force, the launcher can't sufficiently move horizontally. The preliminary design[6][7] is rudder angle that produce opposite force against intention direction, so the case in which the force of the fin is small, the launcher is opposite movement against intention direction. Though preliminary design seemed to be stable, the effect of distance between center of buoyancy and center of gravity can’t handily control the launcher, and it is necessary to decrease the distance in order to exclude the effect. The design shown in Fig2 is difficult to easily decrease the distance between center of buoyancy and center of gravity[8]. Consequentially a mechanism of horizontal movement of without-fin configuration is designed, so the only drive force is rudder force. The positive rudder angle induces positive horizontal velocity.

Table 1 Principal Dimension of Launcher

Note	Dimension
(Fuselage)	
Length overall (m)	3.9000
Parallel body diameter (m)	0.7378
Tail length (m)	0.8432
Tail diameter (m)	0.1845
Weight include AUV in air (kg)	486.0
(Rudder)	
Coord. at rudder axis (m)	-0.7905
Height for unit rudder (m)	0.4216
Cord length at root (m)	0.4216
Cord length at tip (m)	0.2108
Rudder thickness (m)	0.0148
(Fin)	
Coord. at fin center (m)	1.3659
Height for unit fin (m)	0.4216
Cord length at root (m)	0.5270
Cord length at tip (m)	0.3162
Fin thickness (m)	0.0148

III. MODEL EXPREMENT

The model experiment was carried out for the verification of With-fin and Without-fin conditions in respect of whether it did the descending motion that the numerical calculation

Table 2 Launcher Model Dimension

Item Note	With-fin Cond.	W/O-fin Cond.
L (mm): Length overall	845.8	845.8
D (mm): Parallel body diameter	160.0	160.0
Wa (N): Weight in air	142.210	141.135
Ww (N): Weight in water	0.039	0.029

result shows. The experiment of the descending motion was carried out by 1/4.16 scale model of the real size that shows Table 1. Principal dimensions of launcher model are shown in Table 2. Rudder and fin dimensions omitted in Table 2 are similar to those in Table 1. Photograph of the model in without-fin condition is shown in Fig. 3. The model had four rudders that are respectively set manually in every 5 degrees.

Fig. 3 Photographic of Launcher Model

It had a self-control system to prevent twisting motion during descending motion, but this system was not applied to positively of all measurements because the model showed stable descending motion in their experiment. The disconnection was easily possible for four fins. Although the model became a shape that disregarded anchor separation equipment and the small vehicle, we think to become an enough approximate shape for the descending motion verification.

These experiments was carried out using the deep-sea basin[1] at National Maritime Research Institute (NMRI) in Japan that is shown in Fig. 4. The deep-sea basin consists of the circular basin and the deep pit. The principal size of the circular basin is outside diameter 16m (effective diameter 14m) and depth 5m. The deep pit is dug as a cylinder of diameter 6m and depth 30m to the circular basin center bottom. The basin depth is 35m of adding 5m depth of the circular basin in 30m depth of the deep pit. For optical measurement, we used the deep pit monitoring system and the measuring equipment in the pit. The deep pit monitoring system consists of underwater light and underwater color camera (the 1/3 inch CCD camera), and they are monolithic structure. It can move up and down on the pit wall by the winch. It is possible to control the position of the camera remotely, while the monitor of this system in the control room is observed. This camera, instead of the human eye, observes the experiment condition in the pit at real-time. So descending motion were monitored and recorded on videotape. An example of the experiment scene is shown in Fig. 5. The measuring equipment in the pit is the underwater three-dimensional behavior measurement equipment. This equipment is consists of 20 high-resolution digital cameras (10 sets by 2 units/set). This equipment tracks color marker installed in experiment objects such as the mooring line, the riser tube model and thing of moving in the pit etc., and so it

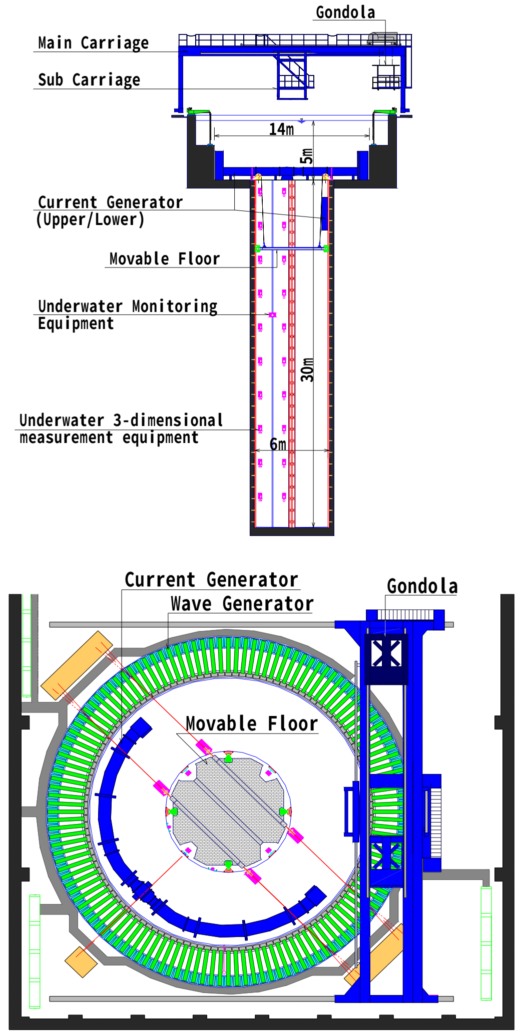


Fig. 4 Outline of Our Deep-Sea Basin

can measure the whole behavior of the object at real time. The red circular mark and the blue and yellow tapes at tail and body of the model in Fig. 3 are targets for measuring system. The blue and yellow tapes are targets for measuring horizontal and vertical movement. The red circular marks, are installed on two faces, are targets for measuring twisting movement. When the model was descended in water, the model set to

Fig. 5 Photographic of Experiment

certain height on water surface, and the model fell freely through the vertical descent mechanism. Model experiment for measuring descending motion was carried out for two types, with-fin and without-fin conditions, of configurations. Weight in water, distance between center of buoyancy and center of gravity, and rudder angle are experimental parameters for both configurations. Particularly, this paper is argued that it is effect of distance between center of buoyancy and center of gravity and it is design of with-fin and without-fin condition, the numerical calculation result shows. Fig. 6 shows time-series data of X, Y and Z motions at the descending movement of that the launcher is with-fin condition and does not use control for preventing twisting motion. The pair's rudder angle is that the launcher conceptually moves to the -X direction, and fixed 15 degrees. Parameter is distance between center of buoyancy and center of gravity, 4.1mm, 8.2mm, 28.2mm and 52.9mm. Fig. 6 (1) shows almost the motion of the preliminary design. Since the twisting motion is generated a little, in the descent after about 24 second, the motion of Y direction is generated. Fig. 6 (2) shows the motion estimated by the calculation. The horizontal motion of the launcher is not generated in this case, since fin force and rudder force become equal, and it is vertical descent. Fig. 6 (3) and (4) show the launcher is opposite movement against intention direction, since the rudder force seems to be bigger than the fin force. There is no difference in comparison with the motion of Fig. 6 (3) and Fig. 6 (4). Vertical velocity is about 0.17m/sec. Fig. 7 shows time-series data of X, Y and Z motions at the descending movement of that the launcher is without-fin condition. Experimental condition and parameter are equal to with-fin. Intending direction in this case is the +X axial direction, because it is only the rudder force. Fig. 7 (1) shows that the twisting motion is generated as well as with-fin, and it is in terms of quantity less than with-fin. The horizontal movement is also almost equal to with-fin. Fig. 7 (2), (3) and (4) show the stable horizontal motion of the Launcher, and all case is same movement. As this fact, it seems to no effect of the distance between center of buoyancy and center of gravity in Fig. 7 (1) of the situation that realistically minimized the distance, it is half horizontal movement in comparison with other figure. It is considered that though clarified reason is uncertain, it is peculiar on this condition. However, it seems to be possible to disregard it, when the real machine is designed, because it is not a realistic distance. Vertical velocity is about 0.165 m/sec.

IV. CONCLUSION

While the launcher descend to sea bottom at about 3000m by gravity, it controls only its rudder for approaching to target point. The model experiment was carried out in order to verify that such descending motion functions effectively in the deep-sea basin at NMRI. For the measurement of the vertical and horizontal motions, the permanent underwater three-dimensional behavior measurement equipment of the basin was used. We compared to the prior numerical calculation result with the measuring result, so the calculation was coincident with experimental. Following facts were confirmed by this experiment.

1) The distance between center of buoyancy and center of gravity has to be sufficiently shortened, if the horizontal movement is carried out by with-fin of preliminary design.
2) It turns out that the without-fin carries out the effective and stable horizontal movement except for that the distance center of buoyancy and center of gravity is very small.
3) In this shape of the launcher, the twisting motion is not very much generated.

It is the future problem that should verify functions of a dispatching equipment of optical fiber cable installed in support vessel, a separation equipment of the anchor for that is fixed on the sea bottom of target point and an equipment of launching the vehicle.

V. ACKNOWLEDGEMENT

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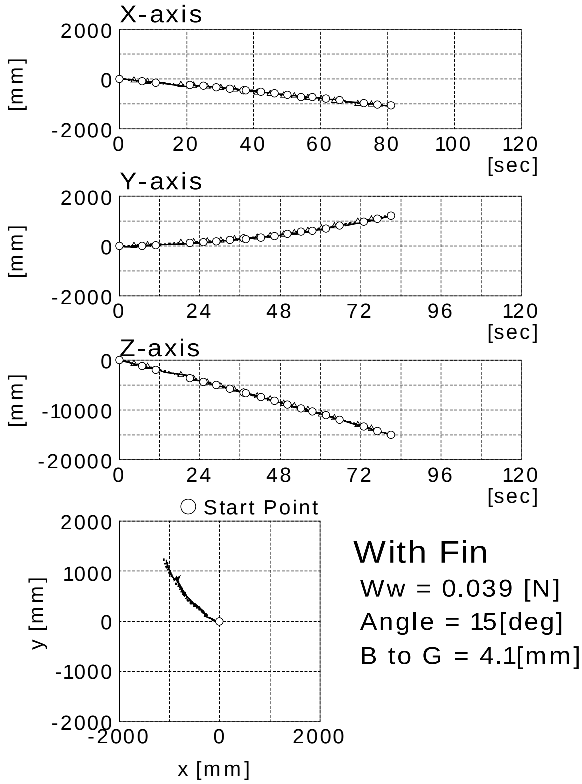

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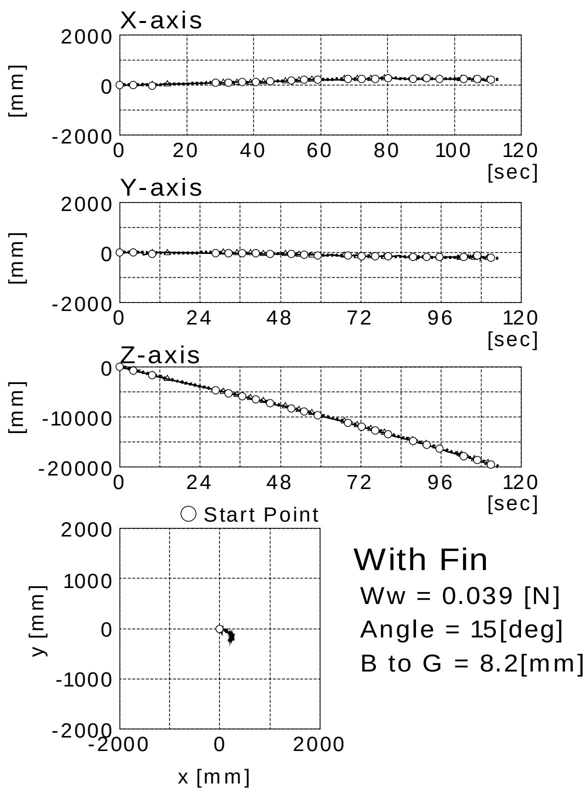

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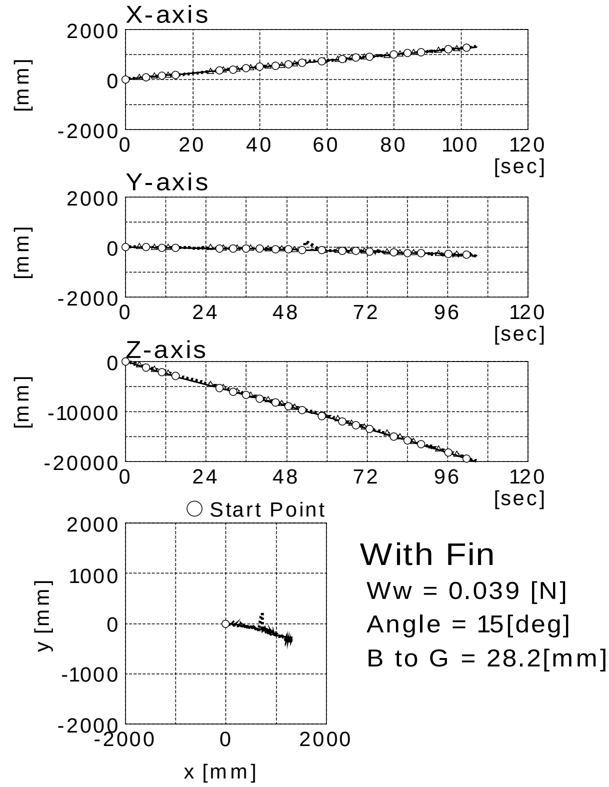

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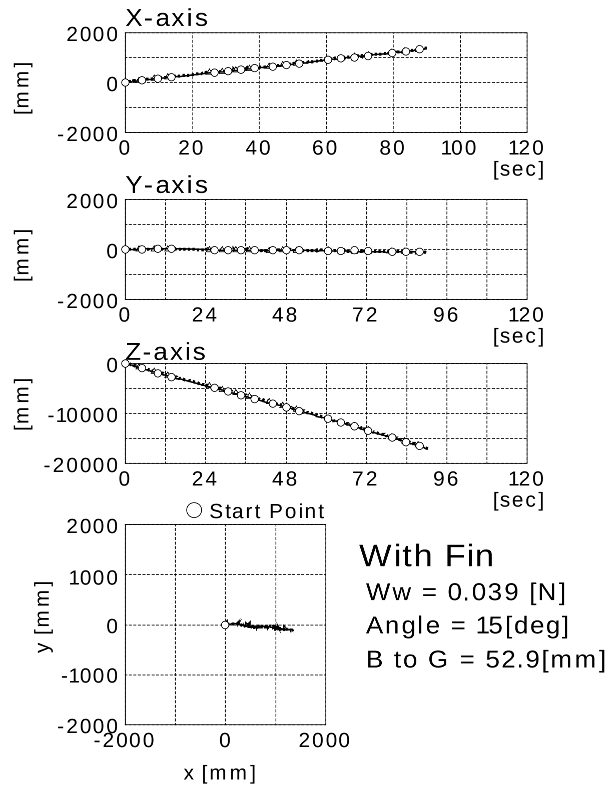

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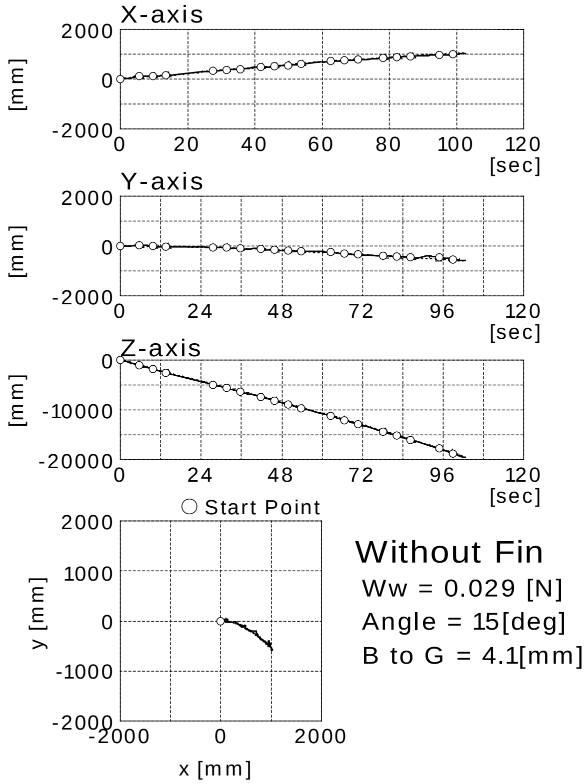
Fig. 6 With-Fin Condition



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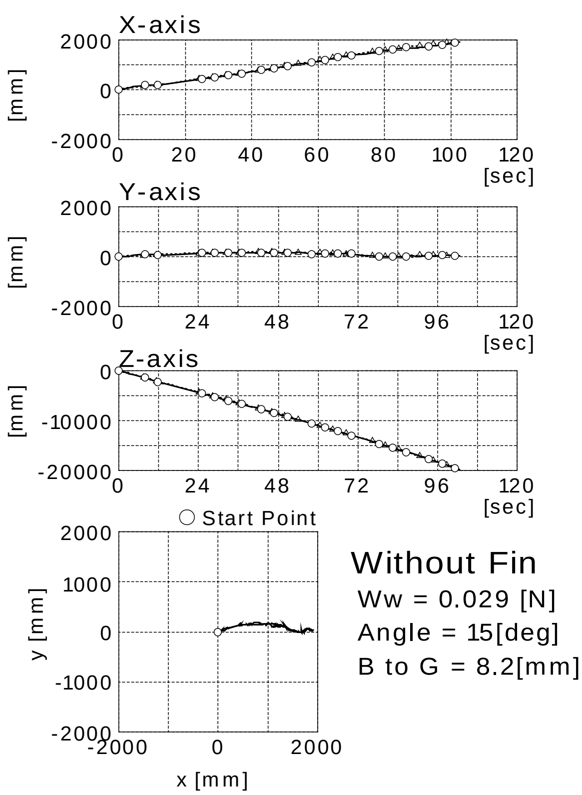

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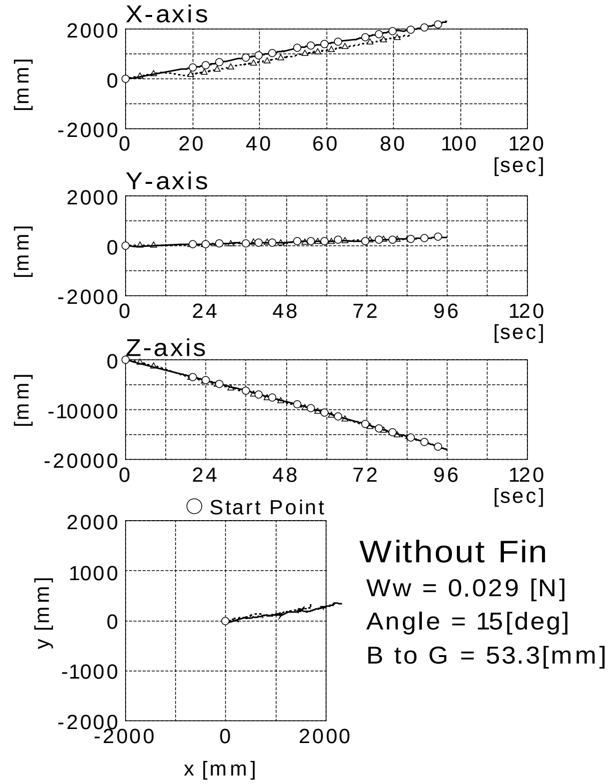

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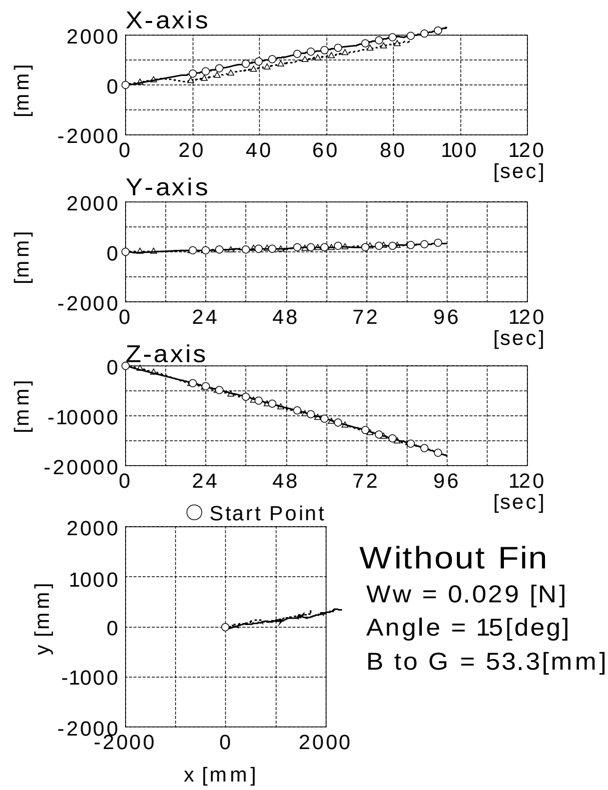

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Fig. 7 Without-Fin Condition