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THE TRANSITION BALLISTIC SIMULATION FACILITY

K Matsunaga[1], K. Sakamoto[2] and S. Hisajima[3]

[1] *Ishikawajima-harima Heavy Industries Co., Ltd., 2-16, Toyosu 3-chome, Koto-ku,*
Tokyo, 135-8733, Japan
2 Ishikawajima-harima Heavy Industries Co., Ltd., 1, Shin-Nakahara-cho, Isogo-ku,
Yokohama, 235-8501, Japan
3 Japan Defense Agency, 2-2-1, Nakameguro, Meguro-ku, Tokyo, 153-8630, Japan

Transition Ballistic Simulation Facility (TBSF) was designed and constructed. The purpose of TBSF is performing the fundamental study of the transitional and exterior ballistics phenomena efficiently and giving the data to design the aerodynamics shape of projectile. Conventional studies on these phenomena were depended on a large number of tests at the firing range and were rather inefficient. TBSF is very unique facility. This paper describes the features of TBSF and typical test results.

Flow visualization by Schlieren method and trajectory sensing by stereo photogrammetry are conducted in TBSF. Characteristics of flow fields around muzzle and projectile can be captured by Schlieren method. Image analysis is conducted to clarify the position and the attitude of the projectile. Then aerodynamic forces of the projectile are given by 6-degree of freedom motion analysis. As acquired data is stored by the data base system, data analysis can be conducted efficiently.

INTRODUCTION

Ballistics is the branch of applied science that deals with the performance of gun systems or rocket launchers. Traditionally, it has been divided into four major research areas (see Fig. 1): 1) Interior ballistics, 2) Transitional ballistics, 3) Exterior Ballistics (Flight dynamics), and 4) Terminal ballistics [1]. Understanding the phenomena of the transitional ballistics is very important for the improvement of the firing accuracy. In the process of transitional ballistics, the propellant gas around the muzzle increases the muzzle velocity of the projectile and changes the attitude of the projectile. The propellant gas flow around the muzzle affects the accuracy of dispersion, through the initial condition of the projectile in the exterior ballistics process. Conventional studies on these phenomena were conducted by a large number of tests at the firing range and were rather inefficient. So, we designed and constructed the Transition Ballistic Simulation Facility (TBSF) that is a facility to conduct the experiments in-door. The purpose of TBSF is performing the fundamental study of the transitional and exterior ballistics phenomena efficiently and

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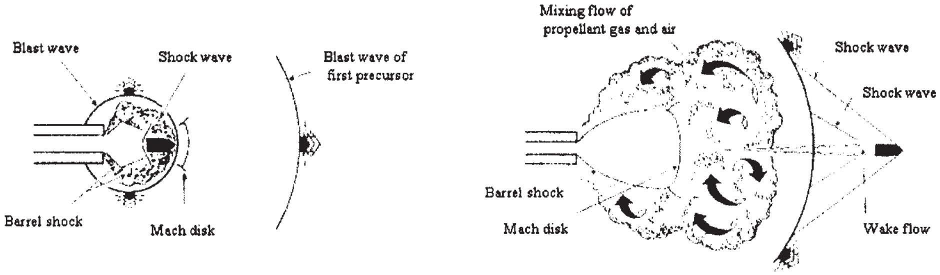
giving the data to design the aerodynamics shape of the projectile. This paper describes the main features of TBSF, some typical results and test plans in the future.



(a) Transition Ballistic (b) Exterior Ballistic

Figure 1: Schematic drawing of the flow field around muzzle.

CONFIGURATION OF TBSF

TBSF is a very unique test facility. This facility consists of three devices – 1) the vertical supersonic wind tunnel, 2) the blast wave generator and 3) the projectile launcher. The over view of TBSF is shown in Fig. 2.

The vertical supersonic wind tunnel is blow-down type and consists of high pressure air supply system, rapidly opening valve with double diaphragms, fixed supersonic nozzles, test section and vacuum chamber. The air supply system has air storage tank of 18.3 m^3 and air compressor pressurized up to 4 MPa. The diaphragms of rapidly opening valve are made of aluminum and are ruptured every test. The supersonic nozzles are 2-dimensional contoured to obtain main flow at Mach number 1.5 and 3.0. The test section has a 0.4 m x 0.4 m cross section and 0.5 m diameter observation windows. The duration time for observation is 0.5 sec.

The blast wave generator is a air driven free-piston type shock tube. The air of the tube is compressed by this driving piston. The pressure in the barrel achieves a maximum value of 100 MPa. The blast wave is generated by rupturing a stainless diaphragm. In the case of transition ballistic test, the projectile is loaded at the root of launcher and can be launched at supersonic velocities.

The projectile launcher is a kind of air gun. The driving maximum pressure is 4 MPa. In the case of exterior ballistic test, the projectile is launched against main flow generated by the vertical supersonic wind tunnel. The launched velocity of the projectile is about 80 m/sec.

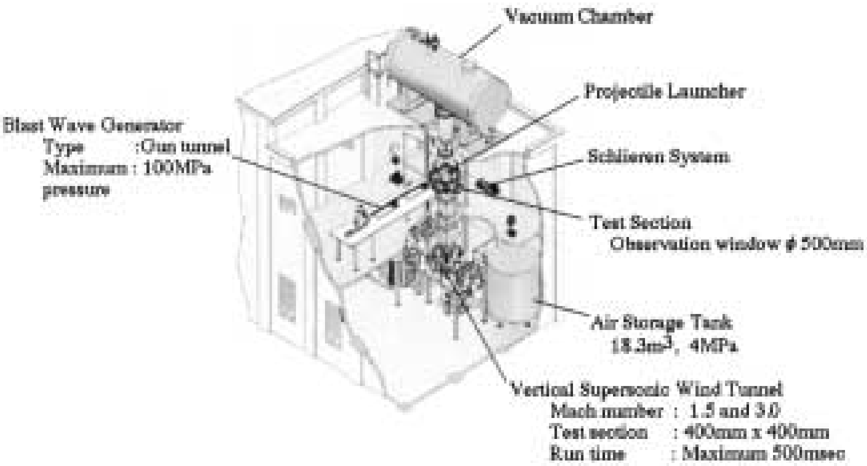


Figure 2: The over view of TBSF.

MEASURING SYSTEM

Trajectory sensing system

A schematic of the trajectory sensing system is shown in Fig. 3. The high-speed video cameras with 512 x 144 pixel resolution are arranged in pairs. The projectile falling down in the test section is recorded simultaneously from orthogonal viewpoints. The framing rate is 2000 fps and exposure time is 23 micro seconds. The edges of the projectile of the recorded digital images are measured. Then the position and the attitude of the projectile are calculated by the coordinate transformation program based on stereo photogrammetry. The accuracy is the location error +/–0.5 mm and angular error +/–0.5 deg. The trajectory and aerodynamic parameters are estimated by the trajectory analysis tool [2].

Schlieren visualization system

The flow fields around the projectile or the muzzle are observed by two sets of Schlieren visualization system (see Fig. 4). The light source is CW green laser. The optical path is bifurcated and orthogonal. Large size concave mirrors (diameter=0.5 m) are arranged. Images are recorded by the high-speed digital framing camera. The framing rate is 10,000 fps and exposure time is 50 nsec. A pair of Schlieren images give a lot of information of the three-dimensional flow fields in the test section.

Database and display system

The acquired images and pressure data are digitized and stored in the database system of TBSF and are displayed by the data display system based on MS-Access. The data display software has friendly GUI and can make animation of the acquired images. All of the measured data can be accessed on the local area network by intranet web site. Thus data analysis can be conducted very efficiently.

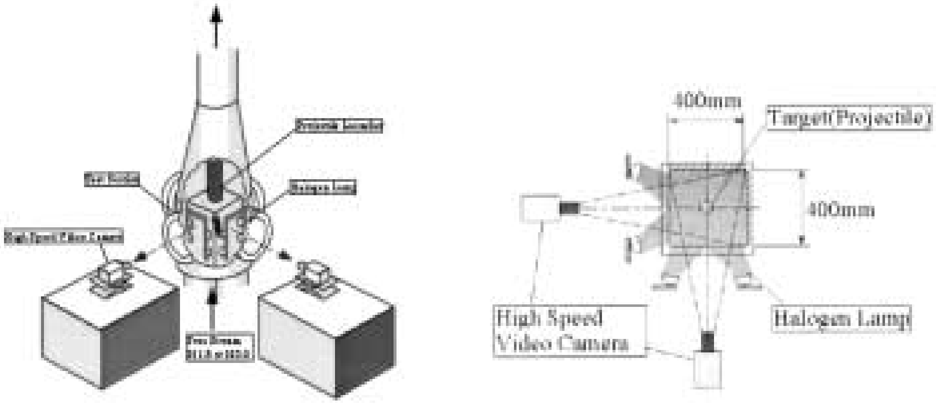


Figure 3: Trajectory sensing system.

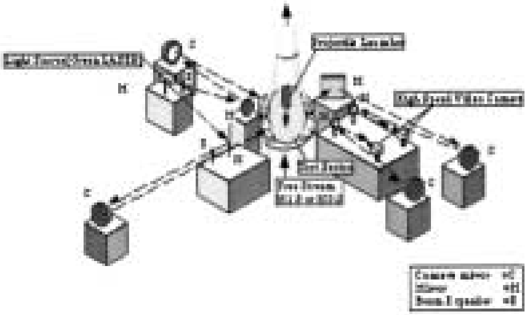


Figure 4: Schlieren visualization system.

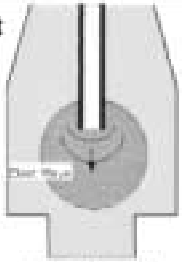
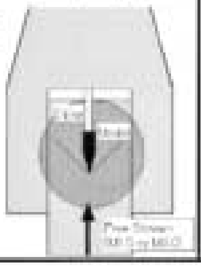
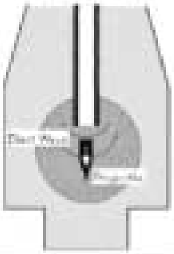
TEST VARIATIONS

This facility can conduct four test patterns – 1) Exterior ballistic test – a) free flight test and b) sting mount test, 2) Transitional ballistic test – c) blast wave test and d) ballistic test. These tests are summarized in Table 1. In the each test, three devices above mentioned are combined suitably and controlled in micro-seconds order.

The free flight test and the sting mount test can simulate the exterior ballistic phenomena. These tests can clarify the behavior of the projectile and the flow field around the projectile at supersonic speeds (M=1.5 and M=3.0). In the case of the free flight test, the vertical supersonic wind tunnel and the projectile launcher are used. The supersonic flow of the vertical wind tunnel is blown up during 0.5 seconds. During this duration time, the projectile is shot by the projectile launcher. The projectile is measured by the trajectory sensing system. The sting mount test is the type of conventional wind tunnel test. The projectile is supported by the sting, which is strut system in the test section, and the Schlieren measurement is conducted in this test.

The blast wave test and the transition ballistic test can simulate the transitional ballistic phenomena. In these tests, the blast wave generator is used. In the blast wave test, the propagating blast wave is measured by the Schlieren visualization system. The flow field around the muzzle can be clarified. In the ballistic test, the high-pressure gas in the barrel drives a light projectile. The projectile is shot down the test section at supersonic velocities. The behavior of the projectile and the flow field around the projectile are measured by the Schlieren visualization system in this test.

Table 1: Test variations

Exterior Ballistic Test	Transitional Ballistic Test
Free Flight Test 	**Blast Wave Test** 
Sting Mount Test 	**Ballistic Test** 

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TYPICAL TEST RESULTS

Exterior ballistic test – free flight test

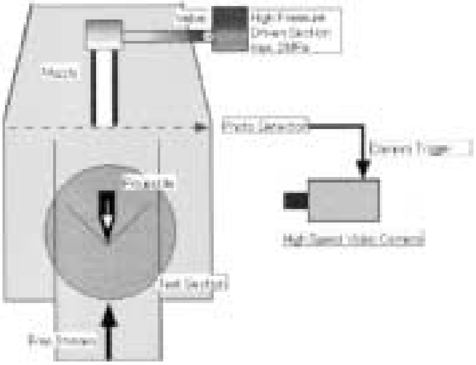
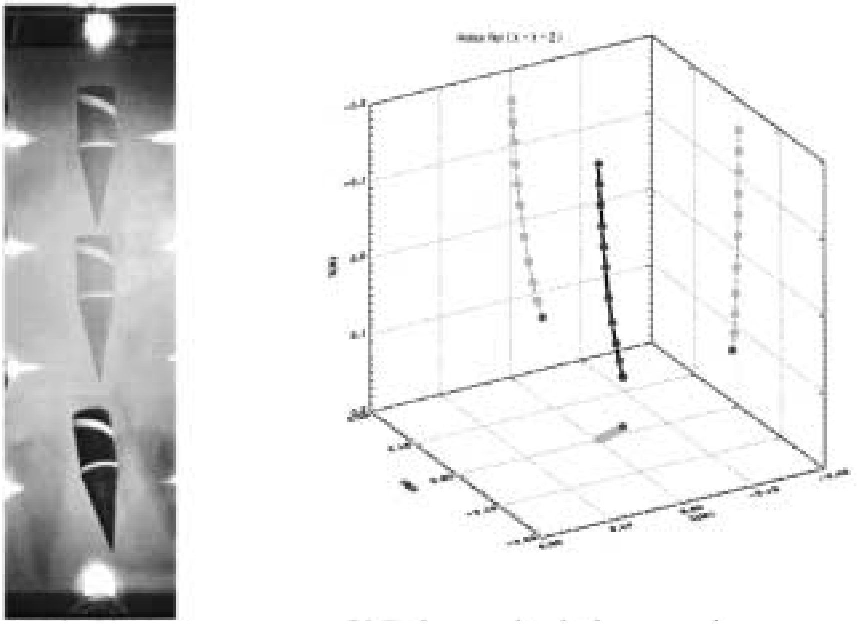


Figure 5: Sketch of the free flight test.

Figure 5 shows the sketch of the free flight test. In this case, the projectile model shape is simplified 150 mm length by 35 mm diameter. The weight of this model is about 200 g. The model is painted with white marks for image analysis. The shot projectile is detected by the photo detector. This step signal starts the high-speed video camera. It takes about 20 msec for the projectile to fall down in the test section. About 10 frame images can be acquired in the measuring time. The recorded images and the trajectory plots are shown in Fig. 6. The recorded images are analyzed by the edge sensing and the coordinate transformation program. In this case, it is found that the projectile is instable and the attack angle becomes large at the down range.



(a) Acquired images (b) Trajectory plots in the test section

Figure 6: The recorded images and the trajectory plots.

Transition ballistic test – ballistic test

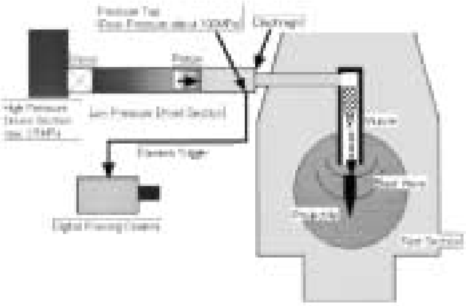


Figure 7: Sketch of the ballistic test.

Figure 7 shows the sketch of the ballistic test. The air of the low pressure driver section is compressed by piston. The pressure achieves up to about 100 MPa and the stainless diaphragm is ruptured and the projectile is driven by this high pressure gas. The high-speed digital framing cameras are started by the step signal of pressure tap at the low pressure driver section. The projectile is 150 mm length by 35 mm diameter.

The weight of this projectile is about 80 g. It is so light that the projectile can be shot at supersonic velocities. Eight frames can be acquired every test. The recorded images are shown in Fig. 8. The typical transitional ballistic phenomena can be captured clearly. Blast wave is propagating in the test section and blast gas (air) is accelating the projectile.

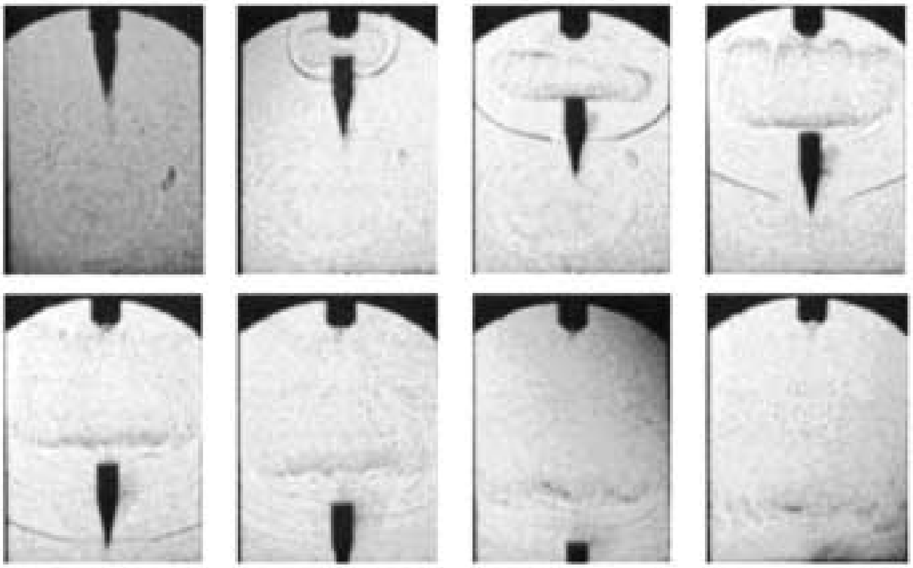


Figure 8: Schlieren images of the ballistic test (framing rate = 10,000 fps, exposure time = 500 nsec).

CONCLUDING REMARKS

The Transition Ballistic Simulation FacIlity (TBSF) was designed and constructed. Model tests on the ballistic phenomena can be conducted in-door by the TBSF. The aerodynamic characteristic of the projectile can be investigated on exterior and transition ballistics. The operation sequence of each test was established. The measurement system engaged in the TBSF was also designed. Trajectory sensing system realized high accurate image analysis. Schlieren measurement system was able to observe the three-dimensionality of the flow fields on transitional ballistic phenomena. Data base system stored all of the acquired data – images and pressure data. Furthermore acquired data were displayed by data display system with friendly graphics user interface. Thus data analysis can be conducted very efficiently.

In the future, TBSF will be employed in order to establish the measuring technique of the ballistics and the test data will be accumulated. The effect of the projectile shape and the muzzle device to the transitional ballistics will be investigated. These test data also will be used to estimate the results of the numerical simulation (CFD). Furthermore we focus on measuring the surface pressure distributions by Pressure Sensitive Paint technique. We have tried to measure the pressure distributions in a very short time less than a micro second.

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