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# STEREO PIV INVESTIGATION OF FLOWFIELDS AROUND A TWO-WHEEL MAIN LANDING GEAR

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**Main subjects**: wind tunnel test, fluid measurement
**Fluid:** subsonic flows
**Visualization method(s):** particle image velocity
**Other keywords:** aeroacoustic, landing gear

**ABSTRACT**: The purpose of this paper is experimental investigation of flowfield related to noise generation mechanism from tire-axle regions of a two-wheel main landing gear. JAXA 2m x 2m Low-speed Wind Tunnel (JAXA LWT2) was used for flowfield measurements. Flowfields around a 40% of two-wheel type aircraft main landing gear model were measured by stereoscopic three-dimensional PIV (Particle Image Velocimetry). In the PIV test, two configurations; the baseline configuration with a backward torque link and configuration without the torque link, were tested. To understand the three-dimensional flow structure, the measurement sections in the freestream direction were set at 10mm intervals. PIV results show asymmetry wake flow for symmetric configuration without the torque link.

**INTRODUCTION.** Due to recent increasing interest in the environmental problems and expected increase in air travel, the regulation of aircraft noise around airport has been severely increased. The noise reduction technology has become one of the key technologies for development of future commercial aircraft. Due to recent efforts for noise reduction from engine, airframe noise became relevant for the overall noise level, especially during approach where engines are throttled down[1, 2]. The noise from landing gears is known to be one of the major sources of the airframe noise besides the noise from high-lift devices[2]. The landing gear mainly consists of an assembly of a number of bluff components. The noise from landing gears represents a cluster of noise sources; broadband noise by turbulent vortex shedding from the structures, interaction of turbulent wake among components, and broadband noise by interaction of shear layer from gear bay[2]. To cover the all noise sources by large streamlined aerodynamic fairing will be effective, but not practical by the penalty from operation, safety, and cost problems such as weight, brake cooling, and maintenance accessibility. To reduce the noise effectively, detail noise generation mechanism from each noise source should be well understood and the effective treatments to reduce the noise are required.

For the research of two-wheel landing gears, NASA has conducted experimental and computational research work on the landing gear of G550[3, 4] collaborating with industries and universities. They have conducted a series of wind tunnel measurements using 25% of the scale model. They found the largest contribution of the torque arm to the noise level and difference of sound pressure level in the mid- and high-frequency range between fully-dressed and partially-dressed configurations.

JAXA has conducted research work on noise generation mechanism and reduction technologies about two-wheel landing gears since 2008[5-7]. The research model geometry and detail components are based on the current two-wheel landing gears design for regional jets. The model includes all detail components such as links, pins, wirings, and hydraulic tubes to reproduce flow field and resultant noise from actual landing gear. In our previous researches about the main landing gear, the overall flowfields and contribution of the model components to the noise level have been investigated by combination with wind-tunnel experiments and CFD-CAA computations. As a result, "Tire and Bogie (Tire-Axle region)" and "Side-brace" were clearly identified as large contributors to the noise generation[5]. In addition, contributions of detail parts such as the wirings and tubes were also shown for a frequency range of the sound pressure level[5]. Flowfield around bogie is complicated with the existence of complicated geometries such as torque link,

brakecaliper, and wheel cap with cooling holes. To clarify the flow structure with complex turbulent flow interactions and the contributions to the noise level will be useful for low noise design.
The purpose of this paper is focused on the investigation of flowfield related to noise generation mechanism from bogie of a two-wheel main landing gear. The unsteady flowfields around bogie are investigated with change of the torque link setting by stereoscopic PIV measurements on the detail geometry.

**EXPERIMENTS.** The experiments were carried out in the JAXA 2m x 2m Low-speed Wind Tunnel (JAXA LWT2; Fig. 1). The LWT2 is a closed-circuit type wind tunnel that has a 2m x 2m rectangular test section. In the 6 m x 6 m settling chamber, honeycomb and wire screens are installed to reduce flow deflection and vortex generation. A relatively high contraction ratio of 9.0 leads to low turbulence in the test section. Uniform flow in this wind tunnel exhibits relatively low turbulence below 0.06 % at 60 m/s for an appropriately seized test section.

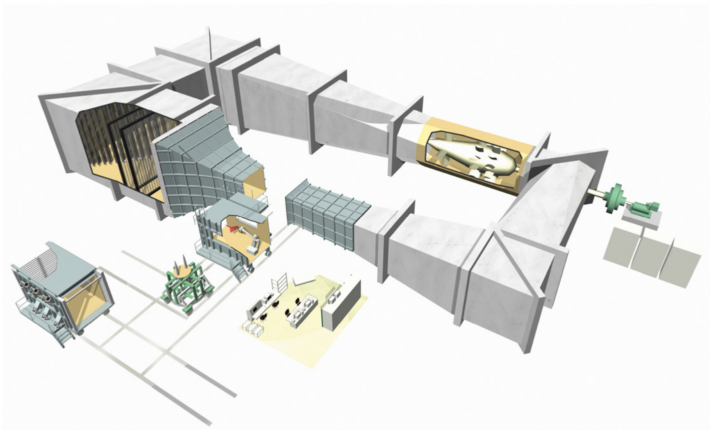
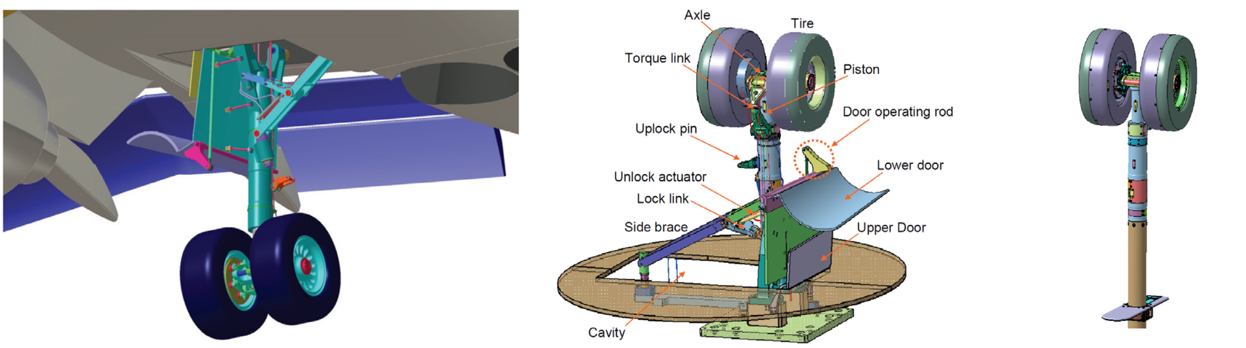


Fig.1 JAXA 2m x 2m low-speed wind tunnel

The research model geometry and detail components are based on the current two-wheel landing gears design for modern 100-PAX class regional jets with wing-mounted engines[5-7]. The model of the nose and main landing gears is called "LEG (Landing gear noise Evaluation Geometry)". The conceptual design was carried out by a landing gear manufacturer in Japan. Figure 2 shows the main landing gear model.

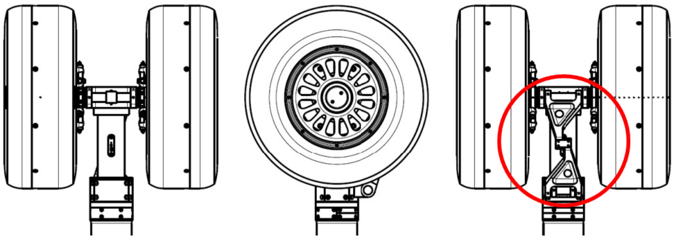



(a) Conceptual design model (b) Fully-dressed wind tunnel model (c) Wind tunnel model for PIV

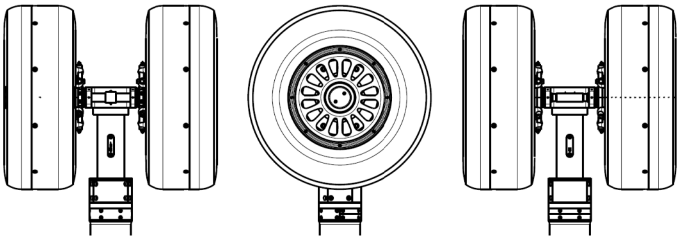
Fig. 2 Two-wheel main landing gear model

From this geometry, a wind tunnel testing model for the main landing gear was fabricated as 40% scale size. The height and tire-diameter are 1.158m and 0.417m, respectively. The wind tunnel testing model includes all detail components such as hydraulic brake caliper, small-links, small-pins, electrical wirings, hydraulic tubes to reproduce the flowfields and resultant noise from actual landing gear. The model can change its configuration from a simple cylinder to fully detail geometry by removing and attaching components to assess the contribution of each component to overall noise level. The configuration equipped with all the components is called "fully-dressed" (Fig. 2 (b)). In the PIV

measurements, the simplified wind tunnel model (Fig. 2 (c)) that is removed components without the torque link from fully-dressed one was used in order to avoid complex laser reflection from attaching components.
Two configurations were chosen in PIV measurements. In CASE1 (Fig. 3 (a)), the model is attaching the backward torque link (red circle in Fig. 3 (a)), and in CASE2 (Fig. 3 (b)), the model is without the backward torque link.



(a) Wind tunnel model with torque link (CASE 1)



(b) Wind tunnel model without torque link (CASE 2)

Fig. 3 Wind Tunnel model configurations in PIV measurements

As shown in Fig. 4, the present stereoscopic PIV system mainly consists of two high-power laser to illuminate the seed particles in the flow, two CCD cameras to acquire images of the illuminated seeding particles, a PC and PIV software (LaVision, DaVis7) to control the equipments and conduct data processing, a stereo calibration plate with a micro adjustment traverse system, and optical components including laser light sheet optics. The lasers are a two-cavity double-pulse Nd:YAG laser with maximum pulse energy of 200 mJ/pulse at a repetition rate of 10 Hz. The cameras are 14-bit monochrome cross-correlation CCD cameras with 2048 x 2048 pixels. While the original frame rate of the camera is 15Hz, three-component velocity vector maps in the stereo PIV measurement are obtained at around 4 Hz due to limitation of data transfer time to a hard disk drive in direct recording condition. The seeding material for the PIV measurement was DOS (dioctyl sebacate). A seeding generator that was developed by DLR was used in the present tests, with the seeding material being delivered by a hose pipe into the tunnel freestream just downstream of the test section[8]. As shown in Fig. 4, a traverse system for both cameras in stereoscopic view and the laser with the light sheet optics was devised, to guide the laser beam through the optical window of the wind tunnel wall.

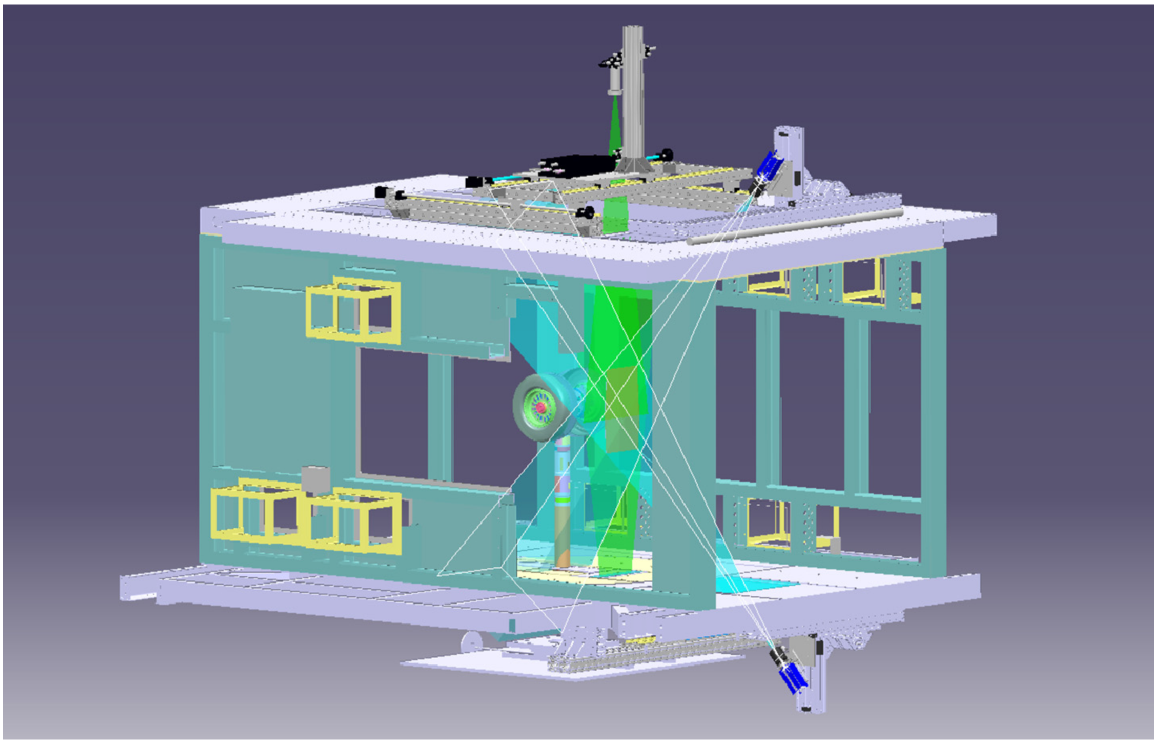
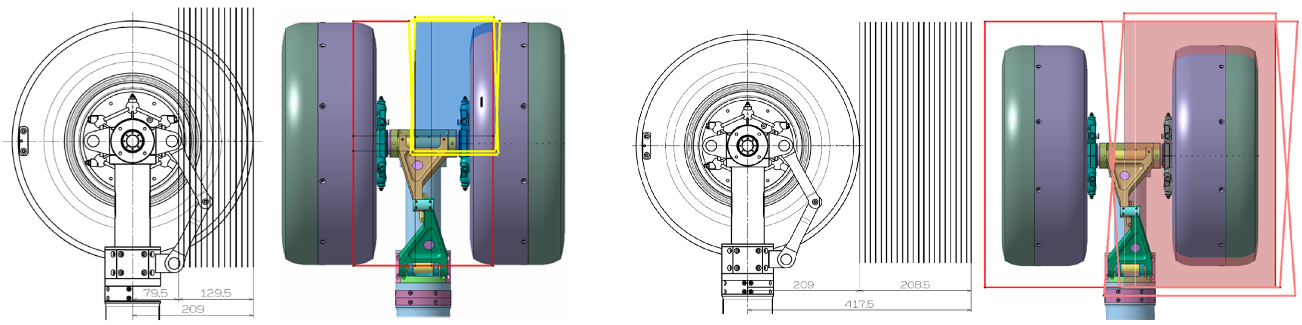


Fig. 4 Stereoscopic PIV setup in the wind tunnel test section

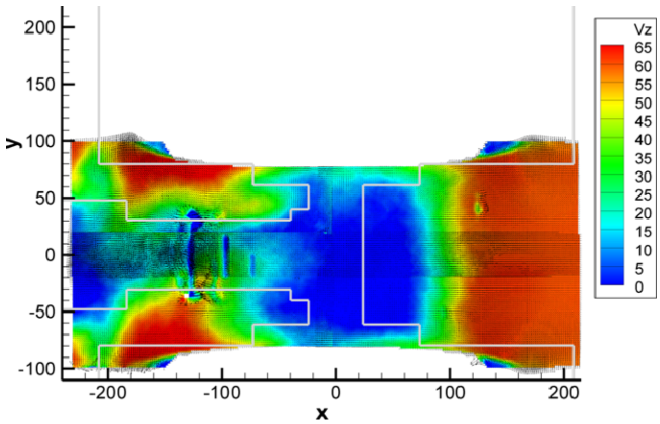
PIV measurement regions are shown in Fig. 5. There are two measurement regions in this measurement. One is tire-axle region (Fig. 5 (a)), and other is tire wake region (Fig. 5 (b)). In tire-axle region, measurement area is divided by four areas in order to improve special resolution. On the other hand, in tire-wake region, measurement area is divided by two areas. The model is traversed at 10 mm intervals to change the measurement plane. In the measurements, 1500 instantaneous three component velocity vector fields were measured in each cross flow plane traversed along freestream direction and *y*-*z* direction. To reduce background noise on the model surface, a subtraction of the average image which was generated by all images in a test case was conducted.



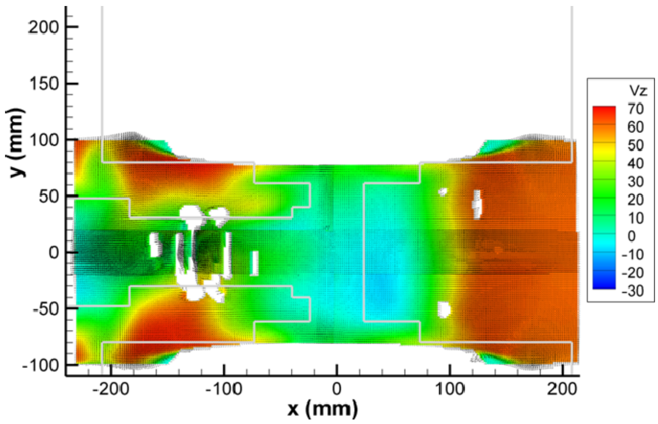

(a) Tire-axle region (b) Tire wake region

Fig. 5 PIV measurement regions

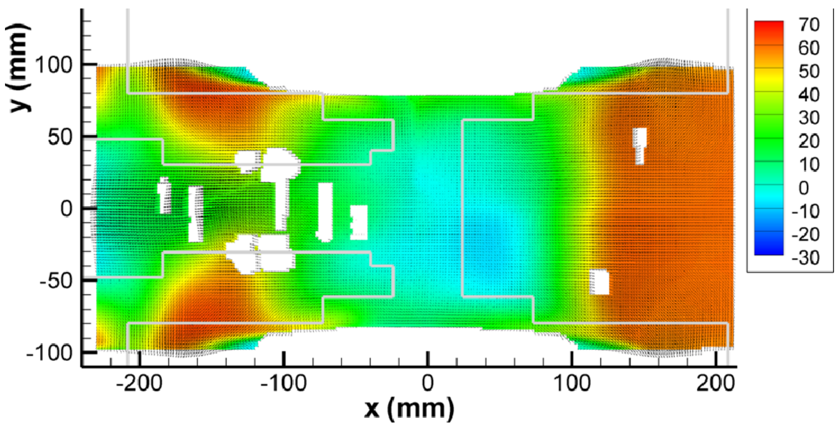
**RESULTS.** Figure 6 shows PIV results in the tire-axle region. In the tire-axle region, it is only the case with the torque link. This is a mean velocity distribution calculated from average of 1500 instantaneous vector maps. Figure 6 (a) shows none post processed data. There are several erroneous vector areas due to halation from the torque link and other parts. Figure 6 (b) shows data removed erroneous vector areas manually. Figure 6 (c) shows post processed data that is merged four measured area. Interpolation method is used in the merge process in order to smoothly data connection. Grid interval of velocity data is set to 2 mm in tire-axle region, and 5 mm in tire wake region. Data luck area due to halation still remains in final post processed data.




(a) None post processed data




(b) post processed data removed erroneous vector areas




(c) Final post processed data

Fig. 6 Mean velocity distributions in tire-axle region

Figure 7 shows final post processed mean velocity distributions in the tire-axle region. Red line in the upper left figure shows measurement plane. Mean velocity distribution is greatly changed with downstream plane. Especially the area between tire and cylinder is very changed from upstream to downstream. There are accelerated flow areas between tire and cylinder, and inversed flow exists behind the axle.

Figure 8 shows turbulence kinetic energy distributions in the tire-axles region. These distributions are treated post processing same as mean velocity distributions. There are strongly turbulence area between tire and cylinder. The area above the axle is also turbulence. Turbulence kinetic energy distribution is greatly changed in the area between tire and cylinder from upstream to downstream.

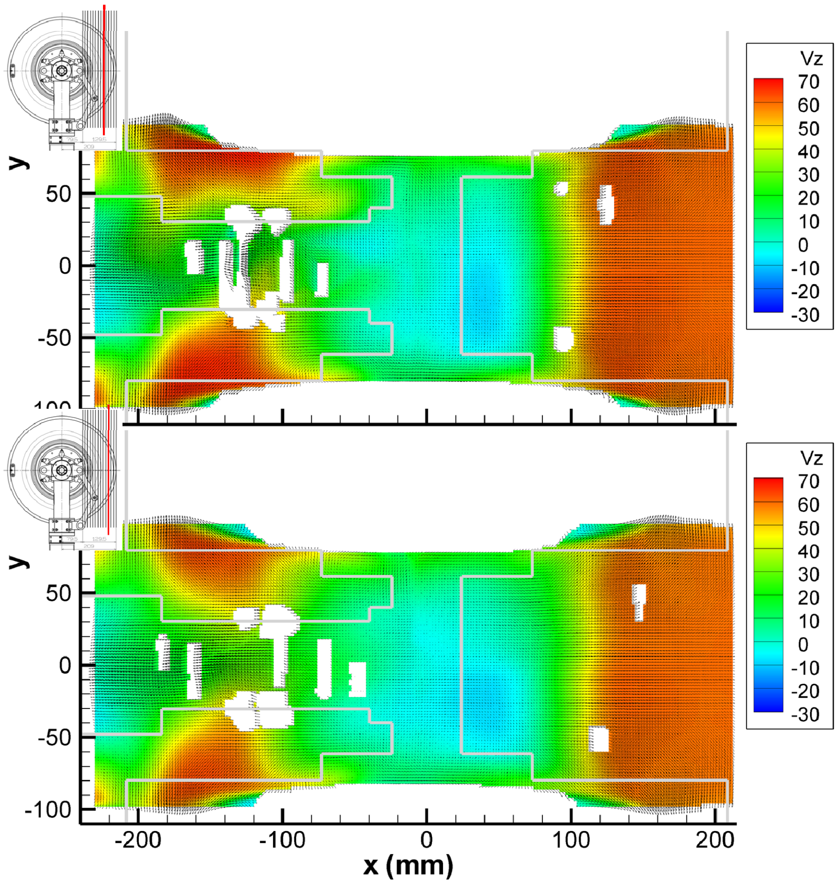



Fig. 7 Mean velocity distributions in tire-axle region

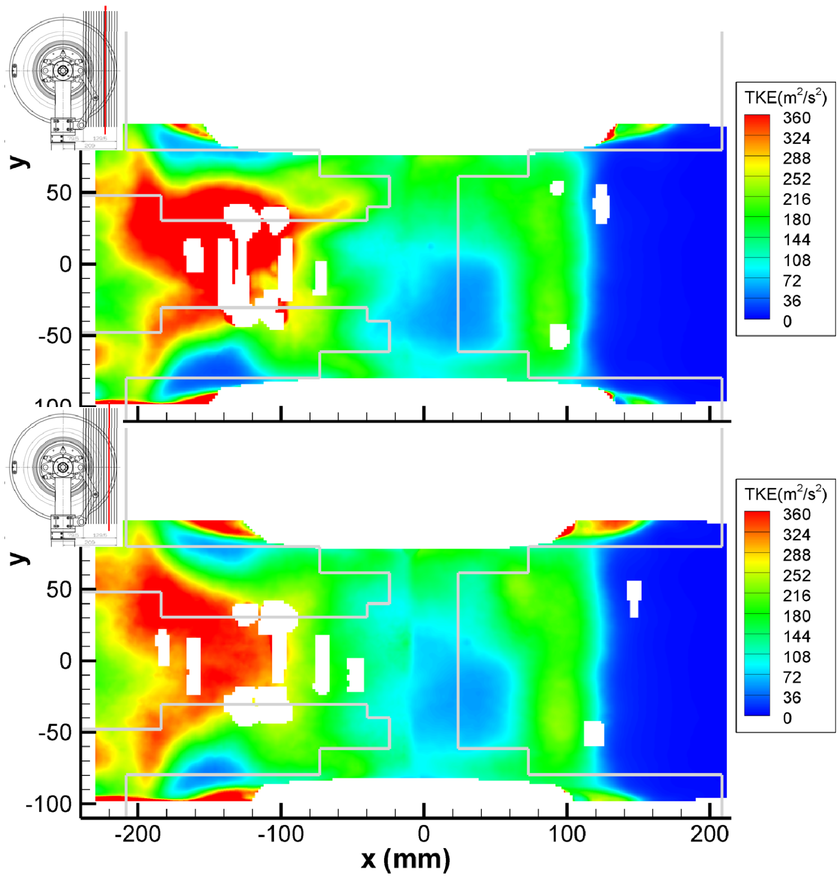
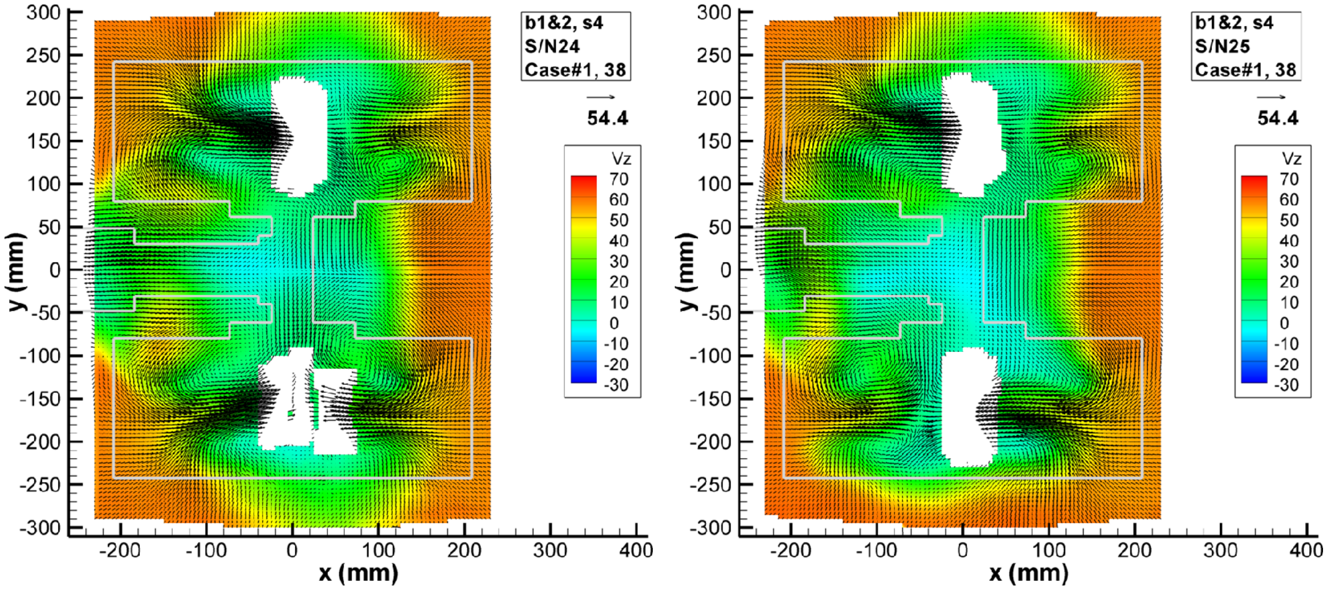



Fig. 8 Turbulence kinetic energy distributions in tire-axle region

Figure 9 shows mean velocity distributions in tire wake region. Figure 9 (a) is a case with the torque link, and Fig. 9 (b) is a case without the torque link. In the case with torque link, there are complex flow structures induced tire, piston and the torque link. Vortex structures exit behind the upper tire area, and accelerated flow exits between tire and piston. In the case without the torque link, there are also complex flow structures induced tire and piston, but acceleration of flow between tire and piston is less than in case with torque link. The model geometry is almost symmetric in the case without torque link. In spite of that, mean velocity distribution is asymmetric in the case without torque link. It is not known exactly why velocity distribution is asymmetric. It may also include influence derived from slight drift angle and swirl in the wind-tunnel or slight asymmetry for the model fabrication and installation in the wind tunnel test.




(a) CASE 1 (with torque link)

(b) CASE 2 (without torque link)

Fig. 9 Mean velocity distributions in tire wake region

**CONCLUSIONS.** The purpose of this paper is experimental investigation of flowfield related to noise generation mechanism from tire-axle regions of a two-wheel main landing gear1, 2. JAXA 2m x 2m Low-speed Wind Tunnel (JAXA LWT2) was used for flowfield measurements. Flowfields around a 40% of two-wheel type aircraft main landing gear model were measured by stereoscopic three-dimensional PIV (Particle Image Velocimetry). In the PIV test, two configurations; the baseline configuration with the backward torque link and configuration without the torque link, were tested. PIV results show asymmetry wake flow for symmetric configuration without the torque link. It may also include influence derived from slight drift angle and swirl in the wind-tunnel or slight asymmetry for the model fabrication and installation in the wind tunnel test.

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