Simulation Technologies for Efficiently Developing Off-road four-wheelers

In our Vision 2030 statement, we at Kawasaki Motors set a sales target of one trillion yen, primarily through our off-road four-wheelers. Achieving this target requires us to launch new, attractive models on the market for time to time. To streamline the development process we are employing simulation technologies, including measurement technology for tire forces, virtual durability testing, and virtual test driving.

Introduction

In North America, off-road four-wheelers (Side × Side) are used for various applications, including agriculture, forestry, hunting, and recreation. Recently, the off-road four-wheelers market has been expanding exponentially as shown in **Fig. 1**. Because many manufacturers have entered this market as a result, leading to fierce market competition, we need to differentiate from competitors and explore new market segments.

1 Background

In our Vision 2030, Kawasaki Motors set a goal of achieving a sales of one trillion yen in FY2030, primarily through our off-road four-wheelers.

Dramatic growth in the off-road four-wheelers business is required to achieve the vision.

2 Policy

The key to growing the off-road four-wheelers business is to develop attractive products ahead of competitors and

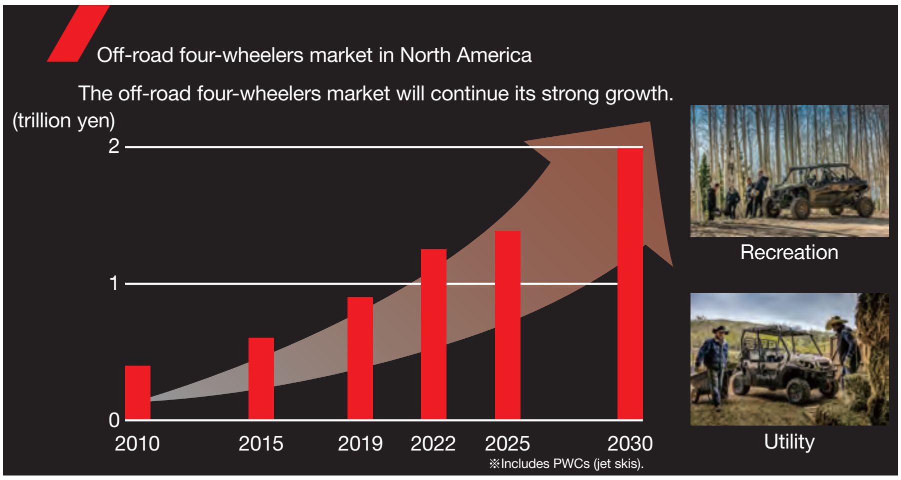


Fig. 1 North America Off-Road Four-Wheelers Market[1)]

launch them early. Therefore, to shorten the development period, we ensure vehicle performance and quality at the initial planning stage, where there is a high degree of design freedom, to reduce rework at the verification phase after vehicle prototyping and decrease development work as a whole (front-loading of development).

3 Issues

Figure 2 is a conceptual diagram of front-loading efforts during durability evaluation. Replacing the durability during real-vehicle evaluation at the verification phase with virtual simulation during detailed design at the design phase decreases rework at the verification phase, which, in turn, reduces the overall work.

Figure 3 is a conceptual diagram of work reduction through front-loading. Work for conceptual design and detailed design at the design phase increases because considerations increase at the initial design stage. However, this is expected to cut problems at the verification phase following prototyping and evaluation, to eventually reduce development work as a whole.

The current issue is to establish a method to achieve such front-loading.

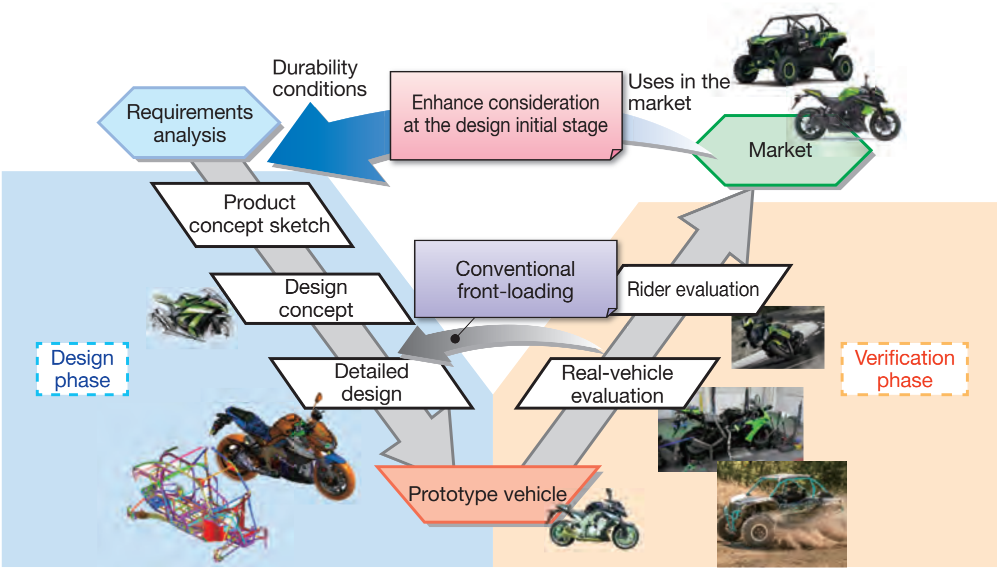


Fig. 2 Front-loading of durability evaluations

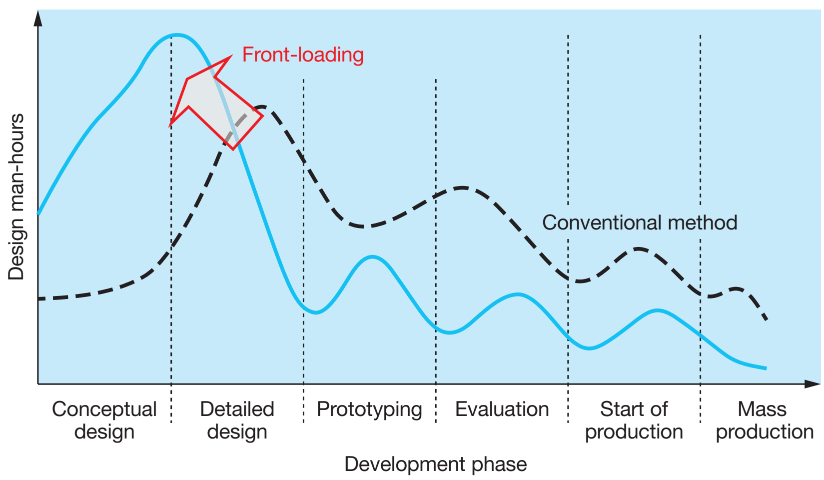


Fig. 3 Reduction in man-hours achieved by front-loading

4 Examples of endeavors

This section shows examples of current endeavors to solve problems toward achieving front-loading.

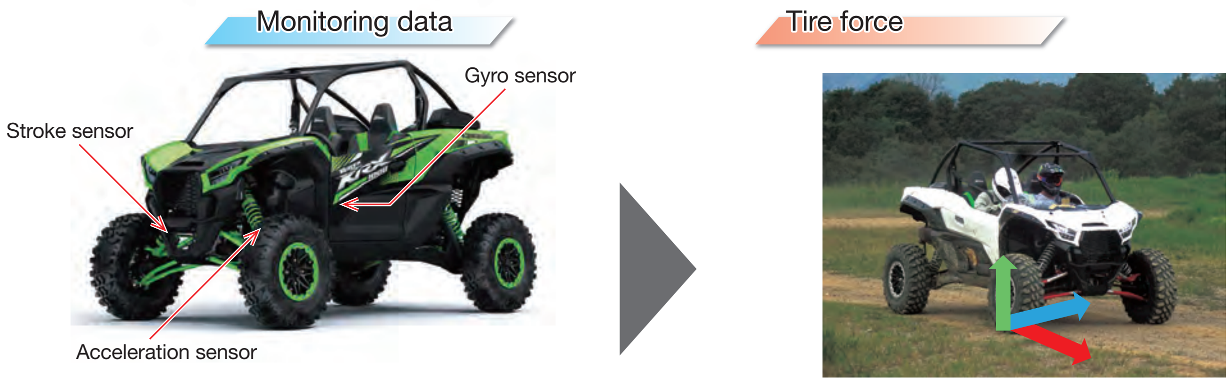
(1) Measurement technology for tire forces

Because external forces are applied to the body via the tires while the vehicle is moving, the body conditions for a durability test run are determined based on tire forces. If the tire forces are incorrectly estimated at the initial stage, rework such as frame repair may result due to insufficient body durability or other causes when the durability of prototype vehicles is checked. Therefore, highly accurate tire force estimation is essential when evaluating body durability.

The tire forces on motorcycles can be estimated relatively easily because they mainly run on flat, paved roads. In contrast, evaluating the tire forces acting on off-road four-wheelers has been more difficult than on-road vehicles because their driving conditions vary widely, from high-speed driving on rough ground or bumpy roads, climbing in rocky sections, and landing after jumps. Therefore, we established a technology to measure the tire forces acting on all four wheels in the off-road environment.

Figure 4 shows the tire force estimation method. We built a logic to estimate the tire forces based on information from the in-vehicle posture angle sensor and other sources.

Figure 5 is a conceptual diagram of tire force estimation. The established method can be used to estimate the tire forces of each element (front, back, right,



(a) Modeling data sample

(b) Conceptual diagram of tire forces

Fig. 4 Measurement method of the tire force [2)]

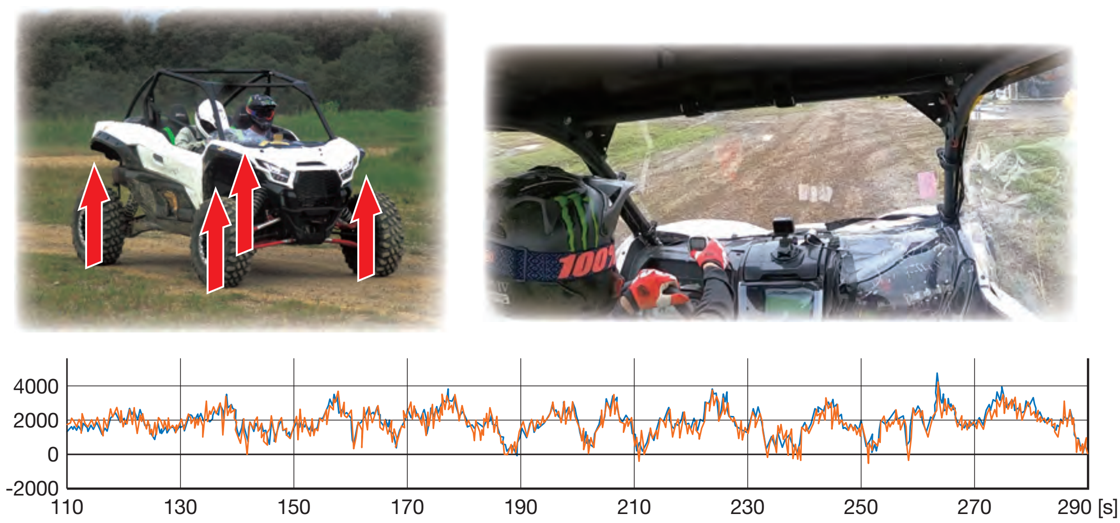


Fig. 5 Measurement of tire forces in action

left, top, and bottom) of four wheels even when the vehicle runs in a rough environment, such as along bumpy roads or landing after jumps.

(2) Virtual durability testing

We expect to prevent problems that may arise during real-vehicle evaluation by estimating the tire forces the vehicle is likely to encounter as it runs in an off-road environment. This will be done through virtual durability testing of the body using the estimated tire forces.

The procedure from the calculating stress on the body frame after tire force acquisition through service life estimation is described below. **Figure 6** shows a conceptual diagram of stress analysis. We can calculate the stress on the frame by applying inertia relief analysis when the tire forces are input. Because tire forces are time history data of when the vehicle runs on a rough road, the frame stress is also calculated as time history data. As the cumulative damage to each part is calculated after the stress time history is derived, the remaining service life of each part can eventually be estimated as shown in **Fig. 7**.

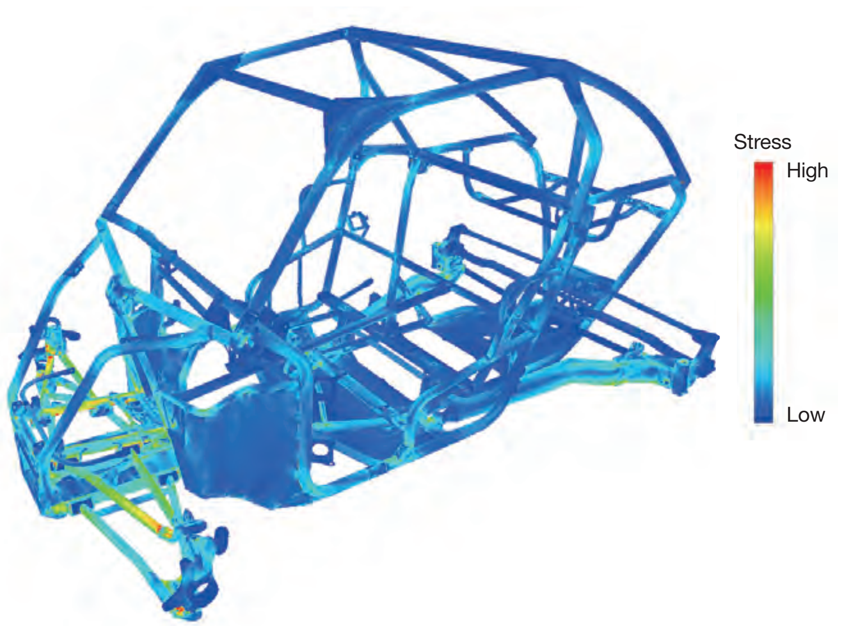


Fig. 6 Image of stress analysis

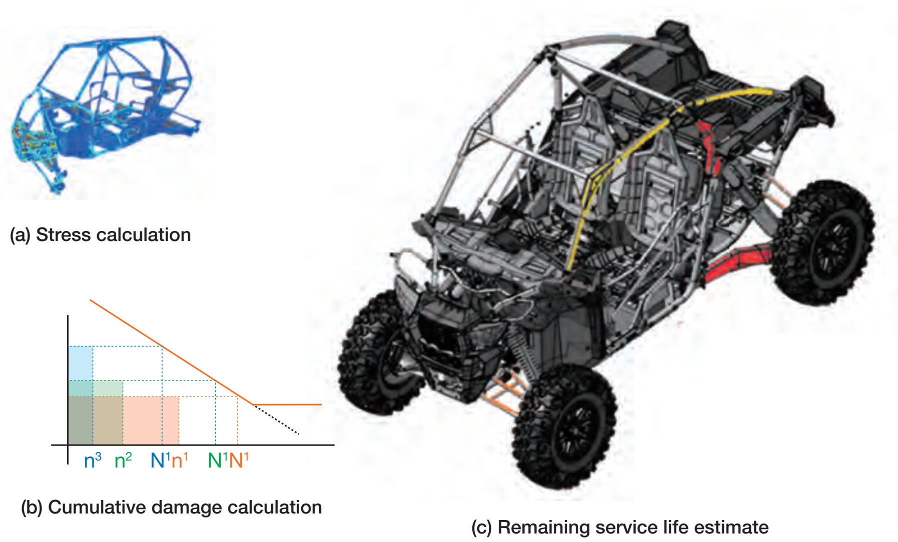


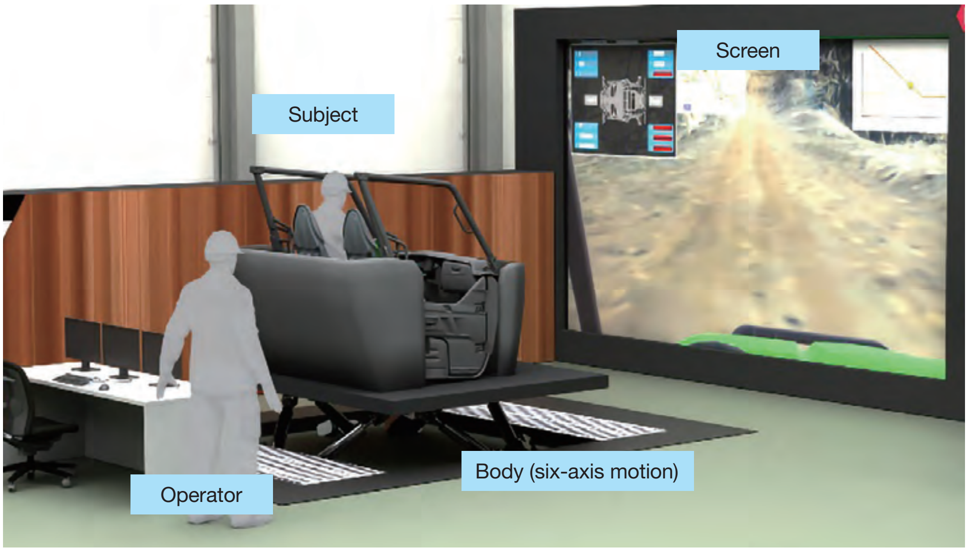
Fig. 7 Image of calculating frame damage

(3) Virtual testing

At the verification phase in **Fig. 2**, the vehicle body is finished based on driver sensory evaluation using a real vehicle. The driver evaluates many different items, including vibration, ride, maneuvering stability, seat positions, and switch operability. If a product fails at the driver evaluation stage, a lot of work and time are required to make the necessary changes. For this reason, we have worked on front-loading by replacing driver evaluation using real cars with virtual testing.

An overview of virtual testing is shown in **Fig. 8**. This environment enables us to build four-wheel vehicle models during simulation and virtually reproduce the behavior of new vehicle models. The driver can virtually drive a new model using a console on the six-axis motion table. The console can be used to operate the accelerator, brakes, and steering, and through the feedback from the six-axis motion the driver can feel vehicle movement such as roll, pitch, and acceleration/deceleration. The driver can also virtually ride existing vehicles and new models for comparison. This virtual testing system has been leveraged, for example, to fine-tune the maneuvering sensation of new models.

Figure 9 illustrates a sensory evaluation result from



(a) Sensor evaluation simulator

(b) Conceptual diagram of driving simulation

Fig. 8 Virtual test driving[3,4]

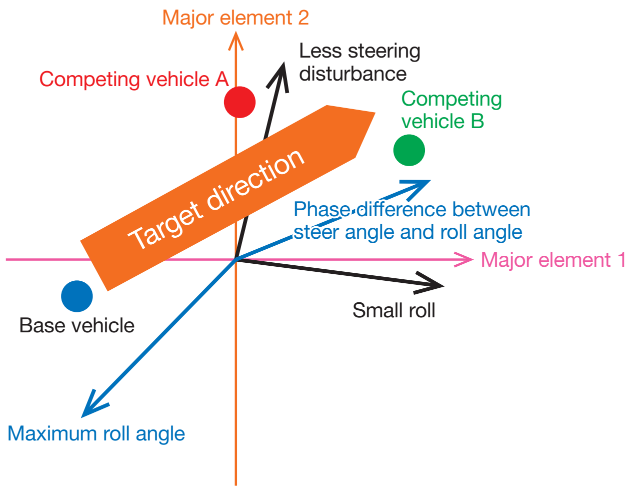


Fig. 9 Example of applying the sensory evaluation method

virtual testing. We expect to apply virtual testing to consider desirable body specifications when finishing a body receives high praise from drivers and passengers in terms of roll motion.

Conclusion

This article has introduced simulation technologies for efficient development of off-road four-wheelers and examples of initiatives to help achieve Kawasaki Motors' 2030 Vision.

We are currently refining the simulator's estimation accuracy for various situations.

In addition, we plan to improve the overall development process, adopting these initiatives, and continue our activities with the goal of significantly reducing development work and time per model as of 2030.

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