A multi-body dynamic model of the snowmobile
to define acting loads in the its parts

D Vdovin¹, Y Levenkov¹,², I Chichekin¹ and A Fominykh¹
¹Bauman Moscow State Technical University, 5 Second Baumanskaya Street,
Moscow, 105005, Russian Federation
²E-mail: levenkov_yy@bmstu.ru

Abstract. In this paper, the snowmobile multi-body dynamic (MBD) model is presented. Mass reduction of the snowmobile parts is the important problem in the process of creating a new vehicle. It is important to determine loads to create rational designs of parts. There are various modeling methods for determining loads. More convenient method is using the MBD model. Research objective: development of the snowmobile MBD model, taking into account the main features of its design. It is possible to perform optimization and strength calculations of snowmobile parts using defined loads at early stages of the development.

Introduction
The snowmobile is the main vehicle in snow-covered regions such as northwest of Russia, Siberia, Nordic countries, Canada etc. It’s designed to be operated on snow and ice and does not require a road or trail, but most are driven on open terrain or trails. For some regions, the snowmobile is the main vehicle for transporting people and goods.

It's known that mass reduction of the snowmobile parts significantly improves the driving performances such as the ride comfort, average speed, fuel efficiency, weights of cargo. Definition of acting loads is the main problem that occurs in the early stages of the development of the vehicle. Development of the snowmobile model has features that are due to the design [1–16].

The presented MBD snowmobile model takes into account main features of the design (front and rear suspensions, steering). Static and quasi-dynamic loading modes are considered. The load calculation is performed using the MBD program [17–26].

Mathematical model of the snowmobile
Dynamic model of the snowmobile «TAYGA PATRUL 551» is shown in Figure 1. This model was performed in the MBD program. Mathematical model of the snowmobile includes: front and rear suspensions, steering, frame. Also inertia mass and mass parameters of its parts are taken into account.

In the model, the following assumptions are made:
– parts of the snowmobile are rigid;
– calculations are performed for gross snowmobile weight;
– joints haven’t internal friction;
– the liquid occupies the entire volume of the fuel tank;
– center of gravity of the snowmobile is constant;
– spring characteristics are linear;
– contact surface is rigid;
– shock absorber characteristics are taken into account.

**Figure 1. MDB model of the snowmobile**

**Snowmobile specifications:**

| Component                                | Weight (kg) |
|------------------------------------------|-------------|
| Gross vehicle weight                     | 600         |
| Frame weight                             | 61          |
| Fuel tank weight                         | 41          |
| CVT and transmission with brake system   | 38          |
| Driver weight                            | 80          |
| Passenger weight                         | 80          |
| Cargo weight                             | 85          |

**Gross vehicle weight distribution:**

| Component                                | Weight (kg) |
|------------------------------------------|-------------|
| Frame weight                             | 61          |
| Fuel tank weight                         | 41          |
| CVT and transmission with brake system   | 38          |
| Driver weight                            | 80          |
| Passenger weight                         | 80          |
| Cargo weight                             | 85          |

**Front suspension:**

- Type: Dependent suspension with a spring strut
- Spring type: Coil spring
- Damper: Hydraulic shock absorber

**Rear suspension:**

- Type: Multi-link suspension with parallel rail designs
- Spring type: Coil spring
- Damper: Hydraulic shock absorber

The front suspension model is shown in Figure 2. The suspension model includes: the spring strut model that was made via spring-damper elements, the interaction of the ski and surface was modeled via contact surface-to-surface. Rotation of the spring strut relative to its axis was modeled via
The revolute joint. Axial movement was modeled via the inline joint. The ski and spring strut connection is made using a bushing joint.

The rear suspension model is shown in Figure 3 and 4. All elements of the rear suspension are interconnected using revolute joints. The upper and lower arms are connected to the snowmobile frame using bushing joints. This method of attachment allows you to automatically transfer the loads at the attachment nodes of the FEM of the frame. Rollers are connected to track using revolute joints. The interaction of the track and surface was modeled using contact surface-to-surface.

**Figure 2.** General elements of the front suspension

Powertrain model consists of a power unit and transmission. The power unit includes an engine, a CVT (continuously variable transmission) and a transfer case. The CVT, transfer case gear ratios and engine’s torque-speed curve are defined in the model by means of an external DLL file. The engine torque is calculated as a function of the transmission rotation speed and accelerator pedal rate and is applied to the front and rear final drives, modelled as rigid bodies with gear coupling ratios. Final drives models also include a locking differential. Torque-speed curves for the power unit and CVT unit [27].

**Figure 3.** General elements of the rear suspension
The frame model is shown in Figure 6. The considered elements of the snowmobile model are connected to the frame.

The developed MBD model allows to simulate statics and dynamics loading cases. In this article is presented two cases: the static equilibrium on a flat road (a reference load event); the snowmobile jump (dynamic event).
Estimation of the results
The static equilibrium on a flat road (Figure 7) and snowmobile jump simulations were performed (Figure 9).

As a result of simulation event produces dynamic the force time history in the suspension, frame, steering joints, etc. As an example, force vs. time diagrams in the strut revolute joint of the front left suspension is shown Figure 8 and 10. Analysis of the force time histories allows to determine the maximum loads to perform strength analysis of the snowmobile parts. Often, one event can produce several load cases.
Besides the maximum loads that determine ultimate strength of the snowmobile parts, it is also possible to simulate regular vehicle rides. These time histories can be used for further fatigue calculations of the snowmobile parts.

![Figure 8](image8.png)

*Figure 8.* Force magnitude vs time in the strut revolut joint of the front left suspension for the static event: $F_x$ — traction force, $F_y$ — lateral force, $-F_z$ — vertical reaction

![Figure 9](image9.png)

*Figure 9.* The snowmobile jump event simulation at $t = 13.55$ s
Conclusions
1. Analysis of the time histories of the forces in the snowmobile parts allows detection of the quasi-static load cases with maximum forces during the event.
2. This maximum loads can be transferred to finite element analysis software for the strength estimation of the parts.
3. Calculated loads can also be used in design optimization process, like topology optimization, at early stages of the snowmobile development.
4. The time histories of the forces can be used for fatigue life analysis of the snowmobile parts.

Acknowledgments
It should be noted that this work was carried out at the Bauman Moscow State Technical University, with financial support from the government in the face of the Russian Ministry of Education under the project: №14.577.21.0272. (Identification number: RFMEFI57717X0272).

References
[1] Hashemi E, Pirani M, Khajepour A, Kasaiezadeh A 2016. *Vehicle System Dynamics* **54** 1736–61
[2] Wei Y, Liu Y, Li X, Oertel C 2016. *Vehicle System Dynamics* **54** 463–73
[3] Taheri M, Ahmadian M 2016. *Vehicle System Dynamics* **54** 653–66
[4] Rodriguez J, Freeman P T, Wagner J, Pidgeon P, Alexander K 2016. *Int. J. of Automotive Technol*. **17** 71–81
[5] Xia X, Xiong L, Sun K, Yu Z P 2016. *Int. J. of Automotive Technol*. **17** 991–1002
[6] Diakov A S, Kotiev G O 2018. *MATEC Web of Conf*. **224** 02096
[7] Evseev K B, Kartashov A B, Dashtiev I Z and Pozdeev A V 2018. *MATEC Web of Conf*. **224** 02039
[8] Kotiev G O, Padalkin B V, Kartashov A B, Diakov A S 2017. *ARPN J. of Eng. and Appl. Sci*. **12** 1064–71.
[9] Sarach E B, Kotiev G O, Beketov S A 2018. *MATEC Web of Conf*. **224** 04009
[10] Klubnichkin V E, Diakov A S, Klubnichkin E E, Zakharov A Y, Vakhidov U Sh, Suchenina A S and Basmanov I V 2019. J. of Phys.: Conf. Series 1177 012048
[11] Volskaya N S, Zhileynik M M and Zakharov A Y 2018. IOP Conf. Series: Materials Science and Engineering 315 012028
[12] Klubnichkin E E, Klubnichkin V E, Kotiev G O 2018. IOP Conf. Series: Materials Science and Engineering 386 012025
[13] Zhileynik M M, Kotiev G O, Nagatsev M V 2018. IOP Conf. Series: Materials Science and Engineering 315 012031
[14] Kotiev G O, Butarovitch D O, Kotsityn B B 2018. IOP Conf. Series: Materials Science and Engineering 315 012028
[15] Skotnikov G I, Jileynik M M and Komissarov A I 2018. IOP Conf. Series: Materials Science and Engineering 315 012027
[16] Ejsmont J, Taryma S, Ronowski G, Swieczko-Zurek B 2016. Int. J. of Automotive Technol. 17 237
[17] Vdovin D, Chichekin I 2016. Procedia Engineering 150 1276–79.
[18] Vdovin D S, Chichekin I V, Levenkov Y Y 2018. Trudy NAMI 1 36
[19] Vdovin, D S, Chichekin I V, Levenkov Y Y, Shabolin, M L 2019. IOP Conf. Series: Materials Science and Engineering 534(1) 012024
[20] Vdovin D, Chichekin I and Ryakhovsky O 2019. IOP Conf. Series: Materials Science and Engineering 589(1) 012025
[21] Volskaya N S, Chichekin I V 2019. IOP Conf. Series: Materials Science and Engineering 534(1) 012022
[22] Lee Y.-L, BarkeyM E, Kang H.-T 2011 Metal fatigue analysis handbook. Practical problem-solving techniques for computer-aided engineering (Oxford, Elsevier) p 581
[23] Gorelov V A, Komissarov A I 2016. Procedia Engineering 150 1322–28.
[24] Gorelov V A, Komissarov A I, Miroshnichenko A V 2015. Procedia Engineering 129 300–7
[25] Levenkov Y Y, Vol'skaya N S, Rusanov O A 2019. IOP Conf. Series: Materials Science and Engineering 534(1) 012023
[26] Keller A V, Gorelov V A, Anchukov V V 2015. Procedia Engineering 129 280–7.
[27] Vdovin D, Levenkov Y and Chichekin V 2019. IOP Conf. Series: Materials Science and Engineering 589(1) 012026