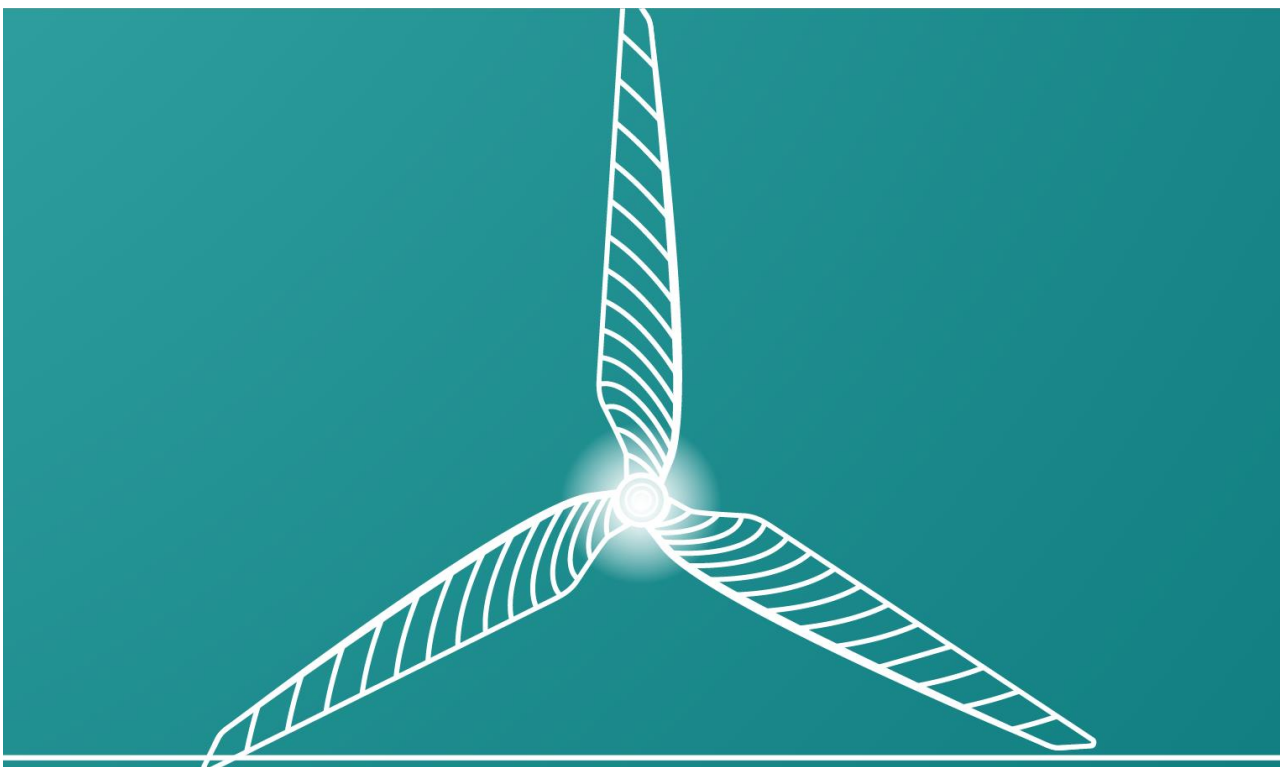


FLEXIBLE GEARED YAW BEARING USER MANUAL

BLADED

Version: 4.12

DNV GL – Digital Solutions



Bladed Flexible Geared Yaw Bearing **User Manual**

Version 3.0

DISCLAIMER

Acceptance of this document by the client is on the basis that Garrad Hassan & Partners Ltd is not in any way to be held responsible for the application or use made of the findings of the results from the analysis and that such responsibility remains with the client.

COPYRIGHT

All rights reserved. Duplications of this document in any form are not allowed unless agreed in writing by Garrad Hassan & Partners Ltd.

© 2020 Garrad Hassan & Partners Ltd.

Garrad Hassan & Partners Ltd.
1 Linear Park Avon Street, Bristol BS2 0PS, UK

<https://www.dnv.com>

Contents

1. Overview	4
2. Description of Yaw Bearing.....	4
3. Defining the Yaw Bearing.....	7
3.1 Project Info.....	7
3.2 Yaw Bearing Definition.....	8
3.3 Interactions with Yaw Control Options in UI	9
4. Logging	9
5. Controlling the Yaw Bearing	10

1. Overview

Bladed provides the facility for users to model a flexible geared yaw bearing in single rotor turbines (not compatible with multi-rotor). This is modelled within the Bladed multibody structural model. This functionality, made available in Bladed 4.12 onward, is activated via a new module written into project info.

This feature is only supported for turbines with an upwind rotor nacelle assembly configuration.

2. Description of Yaw Bearing

The flexible geared yaw bearing is modelled with a yaw gearbox mounted in the nacelle. The component is inserted between the tower top and yaw bearing nodes denoted “TT” and “YB” respectively. A multibody diagram of the system is presented in the diagram below.

The gearbox has a single rotational degree of freedom and has a fixed gear ratio between the low-speed shaft (LSS) and the high-speed shaft (HSS). There are three options for representing the connection between HSS and motor inertia:

1. A rigid HSS with a single concentrated inertia (figure 1),
2. A torsional flexible HSS with a single concentrated inertia (figure 1),
3. Two torsional flexible HSS each with separate inertias (figure 2).

The total inertia of the yaw drives can be represented by either a single inertia or can be represented by two inertias if defining separate load banks. The actuator torque should be applied to the “YBH” nodes and “YBH2” node (if more than one load bank is specified) as denoted on the diagram. More instructions are provided below. The yaw gearbox includes viscous damping and constant friction terms where the coefficients can be specified by the user. The LSS is connected to the tower via a torsional flexibility characterised by rotational stiffness and damping values again specified by the user.

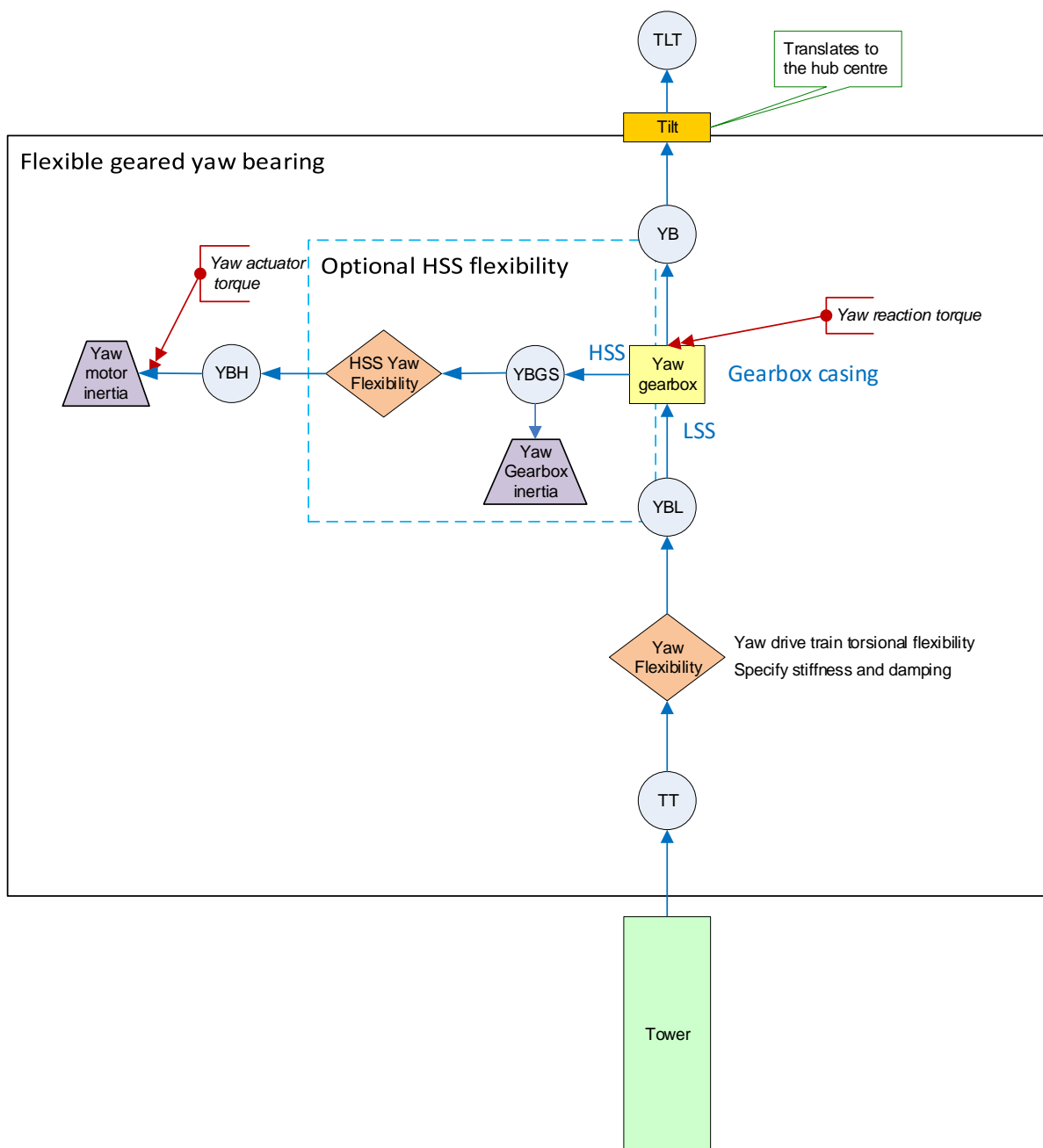


Figure 1: Multibody tree for geared yaw bearing with and without high Speed Shaft (HSS) flexibility

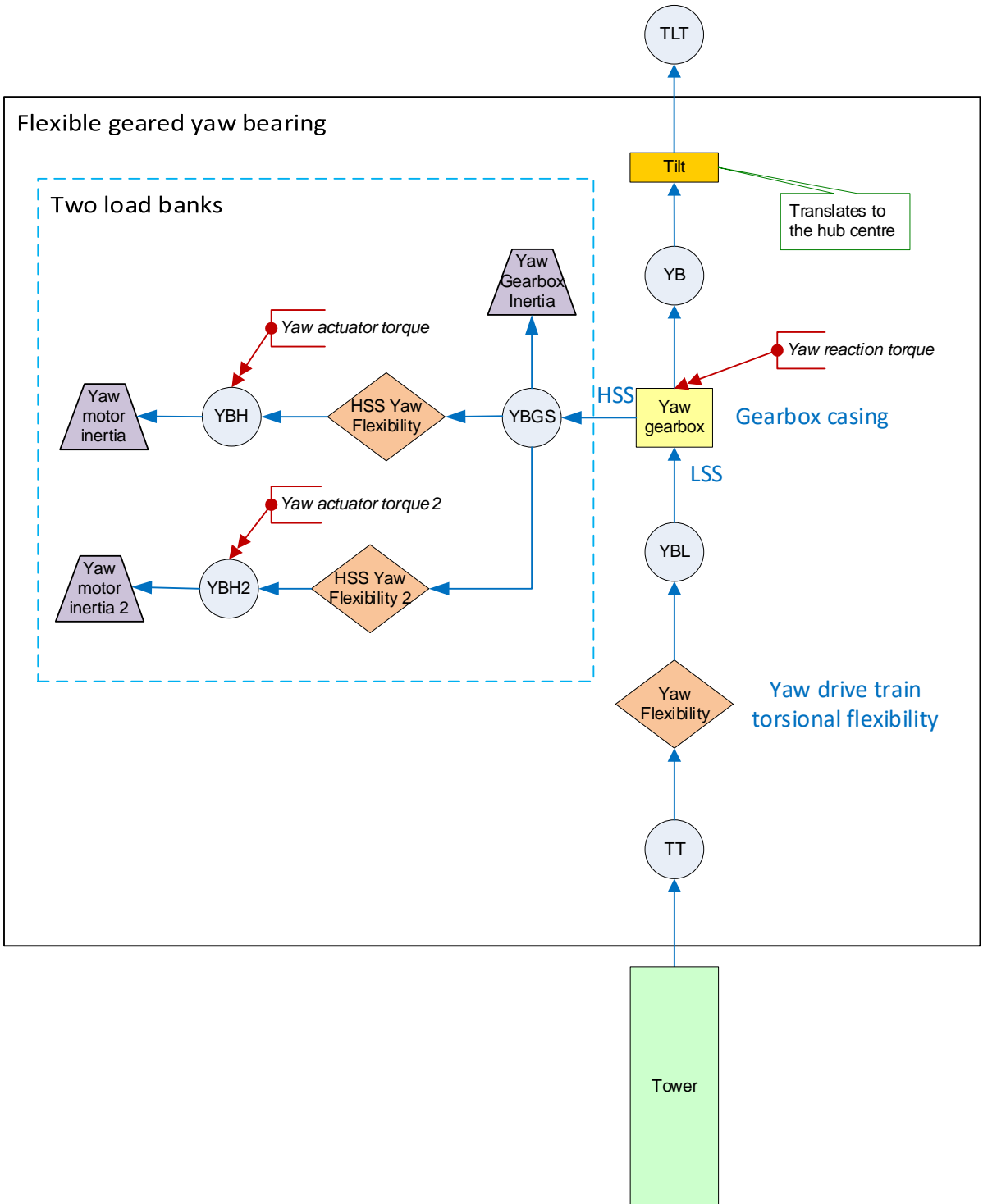
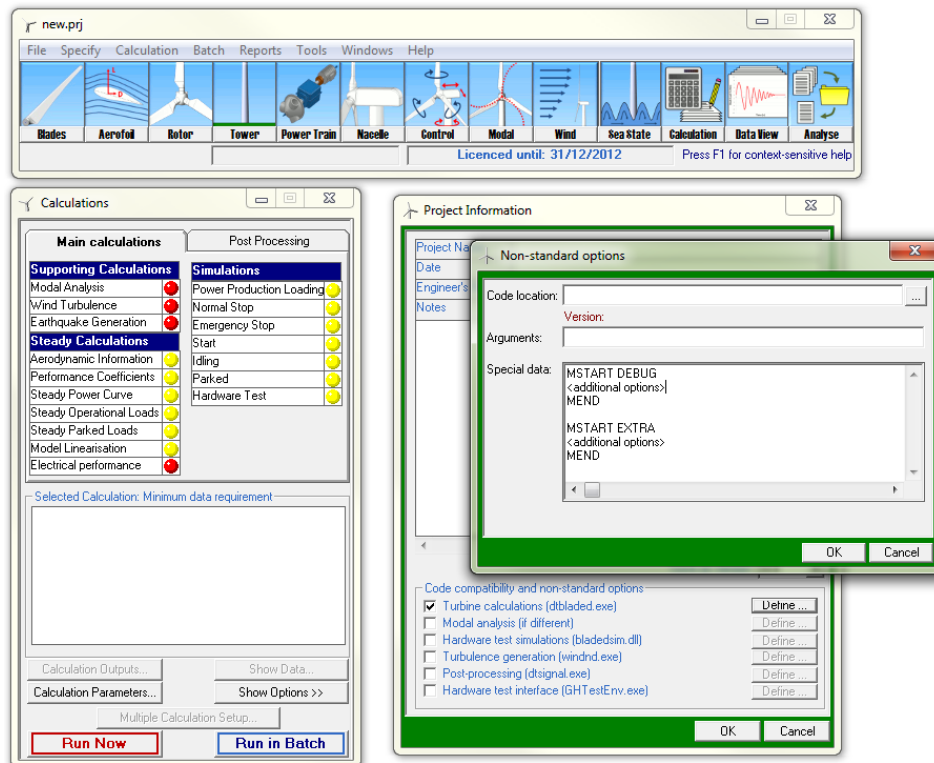


Figure 2: Multibody tree for flexible geared yaw bearing with 2 load banks

3. Defining the Yaw Bearing

3.1 Project Info

The yaw bearing is defined through “Project Info”, which is a free-text field under the project’s properties. These can be defined by going to File → Project Info... and then ticking “Turbine calculations (dtbladed.exe)” and then clicking “Define”:



All three boxes on this dialog are optional, so the “Special data” can be provided without specifying a new executable location or additional arguments.

3.2 Yaw Bearing Definition

The full definition of the yaw bearing input options are shown in the following table. All options are available in Bladed v4.12 onwards.

Keyword	Example Value	Description
MSTART	FLEXGEARYAWSYS	Module start
UseFlexGearedYawSystem	1	Switches the functionality on
NumberOfLoadBanks	2	(Optional) Indicates the number of yaw actuators
JmotorTotal	0.1, 0.1 (kg·m ²)	Total inertia of each actuator (If NumberOfLoadBanks=2, then 2 values are needed.)
GearboxRatio	10000.0	Gearbox speed ratio
YawStiffness	3.0e9 (N·m/rad)	Torsional stiffness of Yaw flexibility component
YawDamping	7.0e7 (N·m/(rad/s))	Torsional damping of Yaw flexibility component
GearBoxDamping	1.0e5 (N·m/(rad/s))	Coefficient of damping/viscous friction for gearbox
GearBoxFriction	1.0e5 (N·m)	Constant rotational friction torque expressed as equivalent friction on the low speed side. Combines internal friction in the gearbox, yaw bearing friction, and minimum friction from brake on the yaw bearing. The applied brake load can be varied using the external loads dll.
LockGearbox	1	Flag to lock the gearbox
ActTorqueLinPerturb	0.001 (N·m)	(Optional) Yaw actuator torque perturbation for model linearization. (If NumberOfLoadBanks=2 then half of the perturbation torque is applied to each actuator).
IncludeHssFlexibility	Y	Include/Exclude HSS flexibility (if NumberOfLoadBanks=2, then IncludeHssFlexibility needs to be set to "Y")
GearBoxInertia	0.1 (kg·m ²)	Moment of inertia of gearbox (referred to high speed side)
HSSStiffness	1.0e6, 1.0e6 (N·m/rad)	Torsional stiffness of High-Speed Shaft (HSS) of each load bank (If NumberOfLoadBanks=2, then 2 values are needed.)
HSSDamping	1.0e6, 1.0e6 (N·m/(rad/s))	Torsional damping of High-Speed Shaft (HSS) of each load bank (If NumberOfLoadBanks=2, then 2 values are needed.)

Notes:

1. Number of actuator load banks is defined by numberOfLoadBanks. This parameter could be 1 or 2. The number of required values for JmotorTotal, HSSStiffness, and HSSDamping is equal to the value of numberOfLoadBanks. If numberOfLoadBanks=2, then user needs to define 2 values for those three parameters.

2. The inertia of the actuators of each load bank is lumped into a value as $J_{\text{motorTotal}}$ of that load bank. Each value corresponds to J_{motor} of a load bank, the inertia of one motor in a load bank, times the numbers of drivers in that load bank.
3. The `GearboxRatio` represents the total gear ratio. We assume this to be the multiplication of the values “Gearbox ratio” and “Pinion to ring gear ratio” provided to us as an example.
4. The parameter `ActTorqueLinPerturb` is optional and only used when carrying out model linearization. It corresponds to the maximum perturbation applied to the yaw actuators to obtain the dynamical response in the linear regime. It must be non-zero. If there are 2 yaw actuators, then half of perturbation torque applied to each of them.
5. If `NumberOfLoadBanks=2`, then “IncludeHssFlexibility” needs to be set as “Y”.
6. If HSS flexibility is switched on, by setting “IncludeHssFlexibility” as “Y”, then values of `GearBoxInertia`, `HSSStiffness`, and `HSSDamping` are required. Note: these values should be positive (greater than zero).

3.3 Interactions with Yaw Control Options in UI

Switching on this functionality disables yaw control options that the user can specify in the user interface (UI) under “Control”->“Yaw control...”->“Yaw control”. When `UseFlexGearedYawSystem=1`, `Bladed` overrides the user’s input in the “Yaw Control” window by setting “Yaw Dynamics” and “Active Yaw” to “None”. A warning is issued to the user. The initial nacelle angle specified under “Calculation Parameters...”->“Initial Conditions” is also inactive in this case.

4. Logging

A Logging group is created for the flexible geared yaw bearing model. It contains the following series:

- Gearbox position and rate.
- LSS flexible hinge position and rate.
- HSS flexible hinge position and rate for each load bank (Note: HSS flexible hinge position and rate outputs for the first load bank are only included when the HSS flexible component is included, i.e. `IncludeHssFlexibility = Y`).
- Motor position and rate for each load bank (Note: motor position and rate are in fact the gearbox position and rate multiplied by the gear ratio. If HSS flexible component is included then; the motor position of each load bank is the summation of the gearbox position multiplied by the gear ratio and HSS flexible hinge position of the corresponding load bank, while the motor rate of each load bank is summation of the gearbox rate multiplied by the gear ratio and the HSS flexible hinge rate of the corresponding load bank).

The positions and rates are given relative to the mounting component. The kinematics are reported relative to the tower top coordinate system. For an undeflected turbine with a vertical tower the angle is measured anti-clockwise (looking down onto the turbine) relative to North.

5. Controlling the Yaw Bearing

The flexible geared yaw bearing can be controlled via the external loads DLL. Torques can be applied to the nodes “YBH” (and “YBH2” if more than one load bank is specified) using the function `ApplyMultibodyNodeTorqueInLocalFrame(const std::string& node_id, const std::string& component_id, const GHEXternalLoads::DOF3& applied_torque)`, where the following arguments should be specified as:

1. `node_id="YBH"` is the name of the proximal node of the “Yaw Motor Inertia” component;
2. `component_id="Yaw Motor Inertia"`, the name of the component on the side of the node where the torque is applied;
3. `node_id="YBH2"` is the name of the proximal node of the “Yaw Motor Inertia 2” component on the second load bank;
4. `component_id="Yaw Motor Inertia 2"`, the name of the component on the second load bank on the side of the node where the torque is applied;
5. `applied_torque` is a vector specifying the applied torque on a node. The applied torque must be of the form $(0, 0, M_z)$ where M_z is the motor torque;

Applying a positive torque results in a positive yaw bearing angle rate and an increased yaw bearing angle.

It is recommended to also apply an equal and opposite reaction torque to where the gearbox casing attaches, e.g. node “YB”

The external loads DLL can communicate with an external controller (written with the application programming interface) via the interface functions `GetNamedUserVariable` and `SetNamedUserVariable`. These functions allow the user to read and write a variable named by the user (for instance “YawTorqueInput” or “YawBearingAngle”, respectively). The named user variables are shared between the external loads DLL and the external controller.