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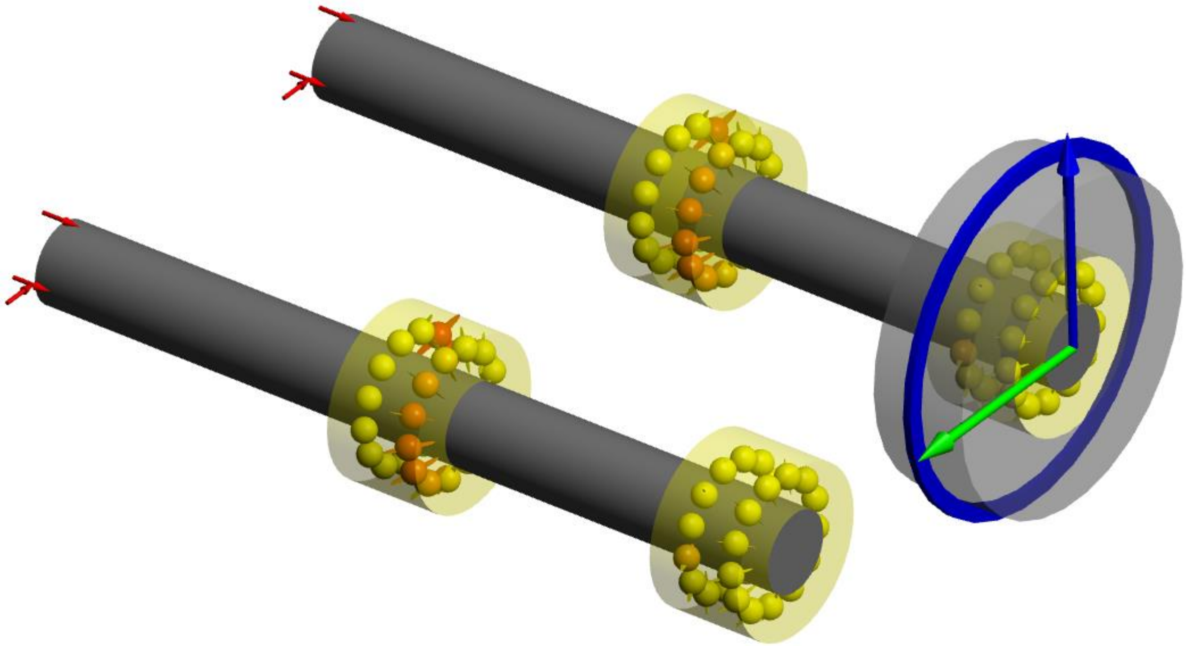
Tutorial: Shafts calculation with angular contact ball bearing sets

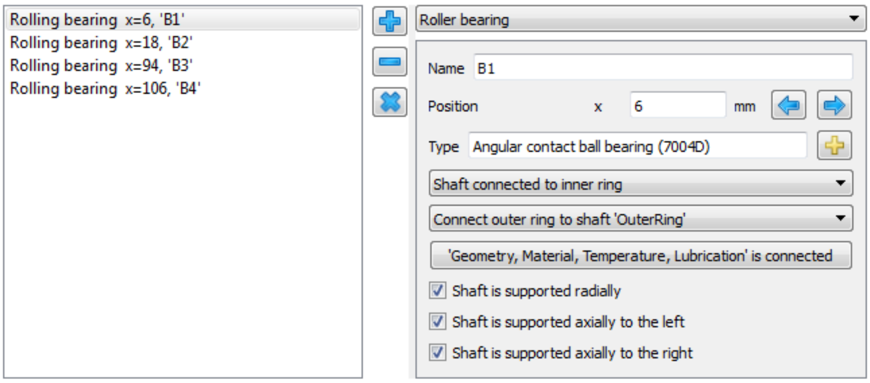
This tutorial will show two possible ways to model sets of angular contact ball bearings on a shaft, while outlining their main differences, as well as exploring the pros and cons of each of them. For the completion of this tutorial, the corresponding calculation file available under downloads is needed.

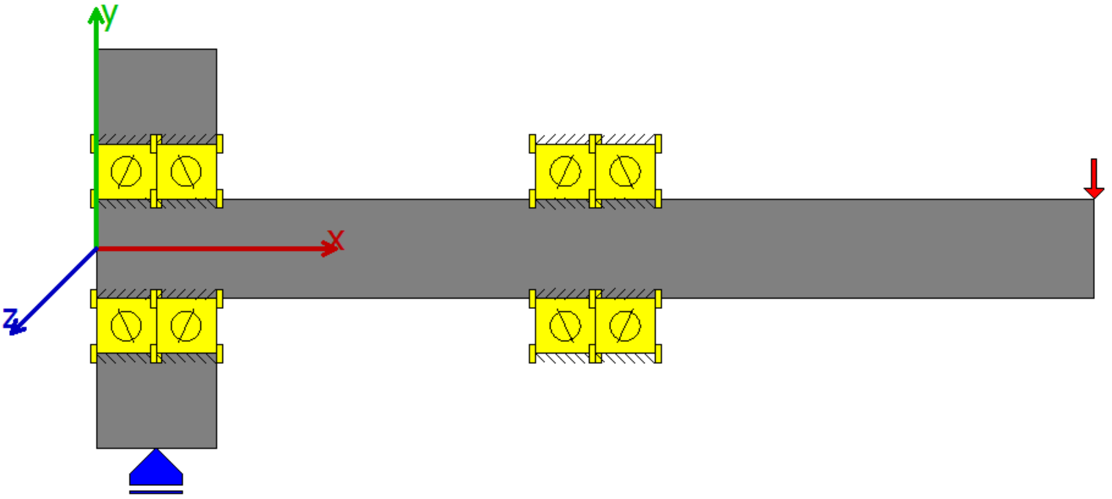


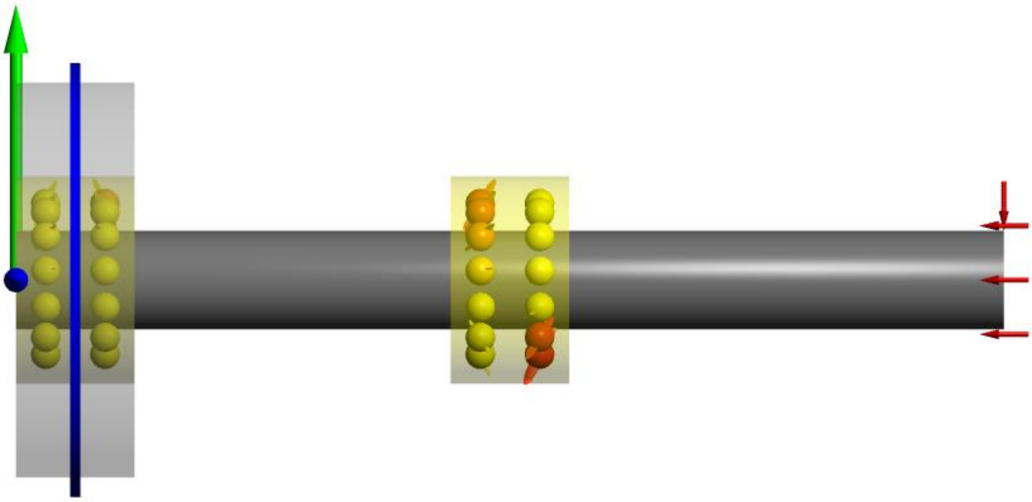
As it can be seen in the picture above, two independent shafts have been created to compare these two alternatives in the same calculation file. A force element consisting of Fx and Fy components is situated at one end of both shafts, which are supported by two sets of bearings mounted in back-to-back configuration. The bearing set located in the center is supposed to be totally fixed and the set located at the opposite end of the load will only support the shaft radially. The boundary conditions resulting from the implementation of these two bearing set arrangements are intended to be equivalent. Let's go a little deeper into the alternatives.

Alternative 1

In this alternative, four single row angular contact ball bearing will be created and conveniently located along the shaft so that the bearings belonging to each of the sets are positioned beside each other:

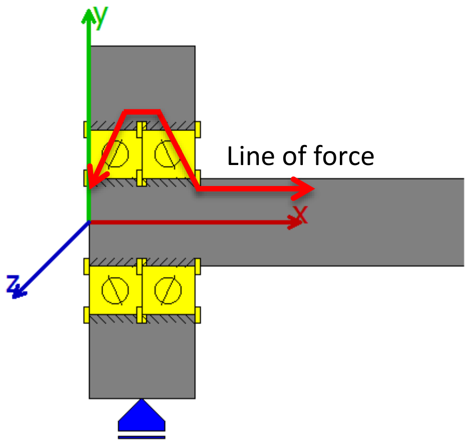


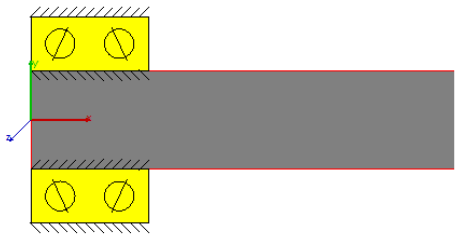




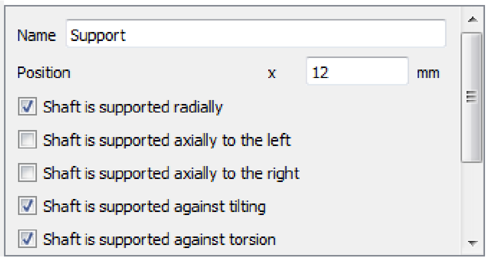
By connecting the outer rings of the bearings located at the middle of the shaft to the housing and setting all the flags corresponding to their supports conditions, the bearing set will behave as a fix support.

However, for the non-locating bearing set, a particular implementation has been carried out, in which two additional elements are needed, i.e. a hollow shaft ('Outer ring') which is in turn radially supported by a single support situated on its outer diameter. The actual outer rings of the bearings will be connected to the hollow shaft, whose purpose is to act as a common housing of the bearings that restricts the free axial movement relative to one another and serve as a load path. Therefore, the support conditions of the two bearings belonging to the non-locating bearing set need to be flagged as fixed:





The support of the hollow shaft will be used to simulate the non-locating boundary conditions of the bearing set, since it will only support the hollow shaft radially and at the same time will also prevent the bearing set from torsion and tilting exactly as the housing would do:



Note that this alternative can be a bit tedious but it will offer more details in our results with regard to each row of balls that form the sets.

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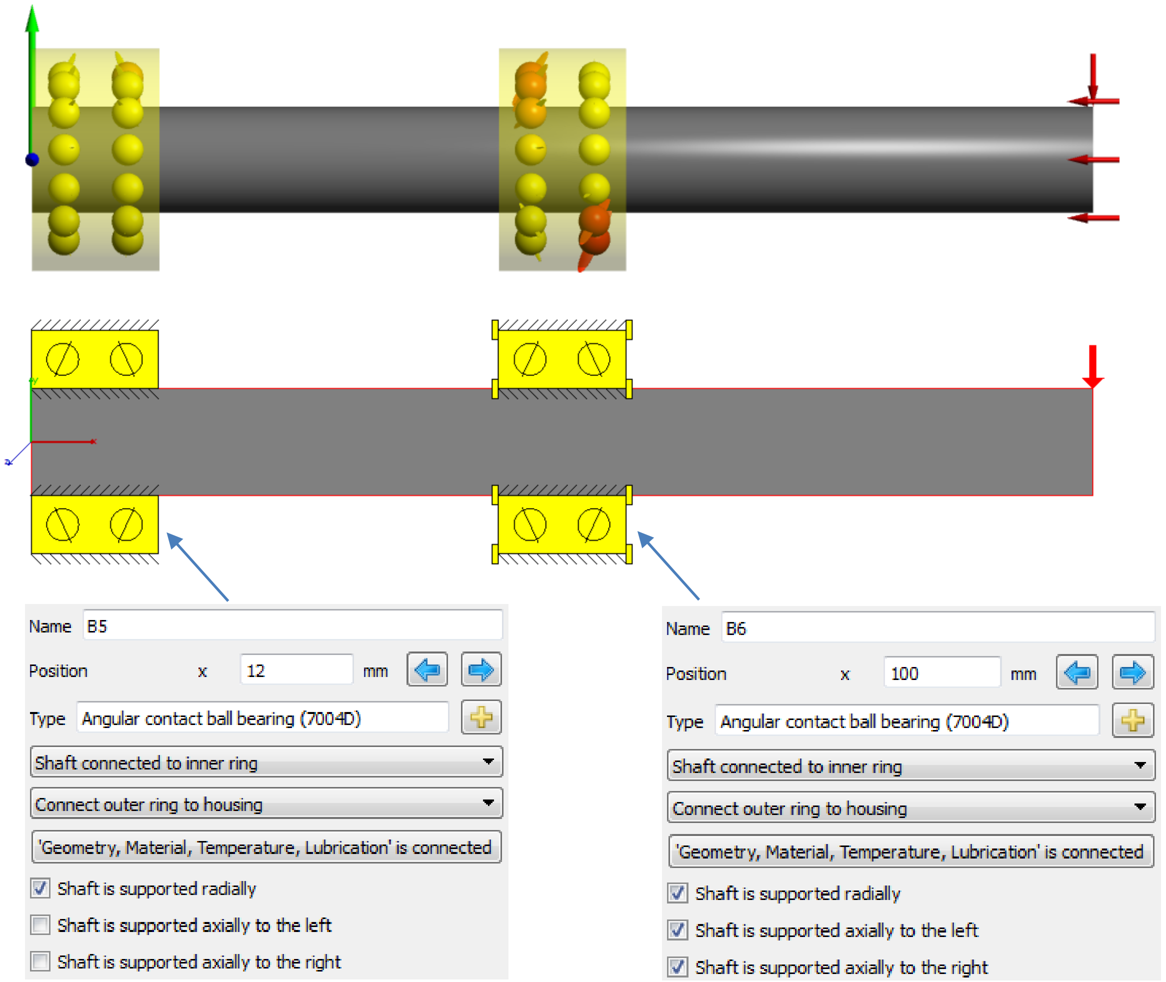
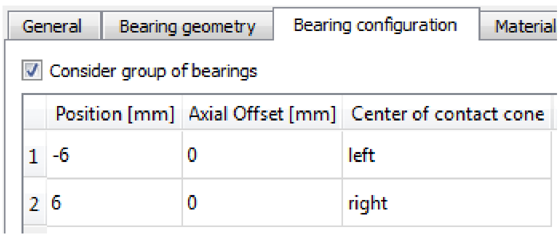
Alternative 2

For this case, only two single row angular ball bearings must be defined first. Then, we will use the software option 'Bearing configuration' in order to create the two bearing sets:



For both sets, groups of bearings are considered so that the corresponding bearings are located next to each other. More specifically, each pair of angular contact ball bearings will be arranged so that the distance of the bearing centers from the group origin is half of the bearing width, i.e. B/2=±6mm:


General | Bearing geometry | Bearing configuration | Material

☑ Consider group of bearings

	Position [mm]	Axial Offset [mm]	Center of contact cone
1	-6	0	left
2	6	0	right

The axial position of the group origins will be determined by the value given for the created single row angular contact ball bearings, i.e. x=12mm and x=100mm.

The housing will be directly connected to the outer rings, under which the displacement of two ball rows is axially restricted, and as result of this configuration, the sets will behave as a double row angular contact bearings, giving rise to shorter life expectancies.

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The main advantage is the ease of deployment. In contrast, if under certain loading conditions one of the rows is not being loaded, it would not be possible have any detailed numerical data with regard to this circumstance. This could only be noticed by means of the load distribution graphic.

Comparison of results

The presented alternatives will in practice give very similar results. In this way, the bearing set 'B5' is the equivalent model of the bearing set 'B1-B2', as the 'B6' is to the bearing set 'B3-B4'.

As mentioned before, having a bearing set modelled by means of the Alternative 1 will provide more detailed information. For instance, it is possible to know the tilting angle 'rz' for both rows of the corresponding set, whereas the 'rz' of the set modelled with the Alternative 2 will have an approximate value (see in green boxes):

Bearing set B5 vs. Bearing set B1-B2

Bearing set B5

Axial load	Fx	0	N	Displacement	ux	0.00470661	mm
Radial load	Fy	686.769	N	Displacement	uy	0.00688737	mm
Radial load	Fz	0	N	Displacement	uz	0	mm
Moment	My	0	Nm	Rotation angle	ry	0	mrad
Moment	Mz	1.09752	Nm	Rotation angle	rz	0.242075	mrad
Speed inner ring	ni	2000	rpm	☑ Inner ring rotates to load			
Speed outer ring	ne	0	rpm	☐ Outer ring rotates to load			
Temperature of shaft	Ti	20	°C	Temperature of housing	Te	20	°C

Bearing set B1-B2

Bearing B1

Axial load	Fx	211.203	N	Displacement	ux	0.00540115	mm
Radial load	Fy	289.478	N	Displacement	uy	0.00535232	mm
Radial load	Fz	0	N	Displacement	uz	0	mm
Moment	My	0	Nm	Rotation angle	ry	0	mrad
Moment	Mz	-2.07751	Nm	Rotation angle	rz	0.291881	mrad
Speed inner ring	ni	2000	rpm	☑ Inner ring rotates to load			
Speed outer ring	ne	0	rpm	☐ Outer ring rotates to load			
Temperature of shaft	Ti	20	°C	Temperature of housing	Te	20	°C

Bearing B2

Axial load	Fx	-211.203	N	Displacement	ux	0.00544349	mm
Radial load	Fy	411.815	N	Displacement	uy	0.00885729	mm
Radial load	Fz	0	N	Displacement	uz	0	mm
Moment	My	0	Nm	Rotation angle	ry	0	mrad
Moment	Mz	2.82009	Nm	Rotation angle	rz	0.263604	mrad
Speed inner ring	ni	2000	rpm	☑ Inner ring rotates to load			
Speed outer ring	ne	0	rpm	☐ Outer ring rotates to load			
Temperature of shaft	Ti	20	°C	Temperature of housing	Te	20	°C

Bearing set B6 vs. Bearing set B3-B4

Bearing set B6

Axial load	Fx	-300	N	Displacement	ux	0.013473	mm	
Radial load	Fy	-1691.61	N	Displacement	uy	-0.0146194	mm	
Radial load	Fz	1.20851e-08	N	Displacement	uz	0	mm	
Moment	My	0	Nm	Rotation angle	ry	0	mrad	
Moment	Mz	-40.6619	Nm	Rotation angle	rz	-1.33663	mrad	
Speed inner ring	ni	2000	rpm	☑ Inner ring rotates to load				
Speed outer ring	ne	0	rpm	☐ Outer ring rotates to load				
Temperature of shaft	Ti	20	°C	Temperature of housing	Te	20	°C	

Bearing set B3-B4

Bearing B3

Axial load	Fx	929.608	N	Displacement	ux	0.0142107	mm	
Radial load	Fy	585.026	N	Displacement	uy	-0.00524127	mm	
Radial load	Fz	0	N	Displacement	uz	0	mm	
Moment	My	0	Nm	Rotation angle	ry	0	mrad	
Moment	Mz	-6.07224	Nm	Rotation angle	rz	-1.11182	mrad	
Speed inner ring	ni	2000	rpm	☑ Inner ring rotates to load				
Speed outer ring	ne	0	rpm	☐ Outer ring rotates to load				
Temperature of shaft	Ti	20	°C	Temperature of housing	Te	20	°C	

Bearing B4

Axial load	Fx	-1229.61	N	Displacement	ux	0.0143822	mm	
Radial load	Fy	-2291.16	N	Displacement	uy	-0.0208981	mm	
Radial load	Fz	-3.71506e-08	N	Displacement	uz	0	mm	
Moment	My	0	Nm	Rotation angle	ry	0	mrad	
Moment	Mz	-16.4334	Nm	Rotation angle	rz	-1.62806	mrad	
Speed inner ring	ni	2000	rpm	☑ Inner ring rotates to load				
Speed outer ring	ne	0	rpm	☐ Outer ring rotates to load				
Temperature of shaft	Ti	20	°C	Temperature of housing	Te	20	°C	

It is noteworthy to have a look at the radial forces ‘Fy’ of B1-B2 and of the support of the shaft ‘Outer ring’ (see red boxes in the picture below). The sum of the radial forces ‘Fy’ of B1 and B2 should be equal to the resulting radial force in the support, but in practice it is a little bit higher:

$$0.701\ kN = \mathrm{Fy}_{\mathrm{B3}} + \mathrm{Fy}_{\mathrm{B4}} \neq \mathrm{Fy}_{\mathrm{support}} = 0.695\ kN$$

The reason why this equation is not fulfilled is because the weight of the outer ring has been taken into account, and its corresponding force is counteracting the bearing forces, so the correct equation is:

$$\mathrm{Fy}_{\mathrm{B3}} + \mathrm{Fy}_{\mathrm{B4}} - \mathrm{F}_{weight} = \mathrm{Fy}_{\mathrm{support}}$$

Name	L10h [h]	Lnmh [h]	L10rh [h]	Lnmrh [h]	pmax [MPa]	SF	Fx [kN]	Fy [kN]	Fz [kN]	Mx [Nm]	My [Nm]	Mz [Nm]
Shaft 1												
B1	311331	6981100	363791	9281168	1396.61	27.20	0.211	0.289	0.000	0.00	0.00	-2.08
B2	123311	1384480	110794	1157026	1674.74	15.77	-0.211	0.412	0.000	0.00	-0.00	2.82
B3	7469	18416	13520	43433	1959.75	9.84	0.930	0.585	-0.000	0.00	-0.00	-6.07
B4	716	763	634	651	2909.12	3.01	-1.230	-2.291	-0.000	0.00	0.00	-16.43
OuterRing												
Support							0.000	0.695	0.000	0.00	0.00	1.48
Shaft 2												
B5	107293	1556997	101953	1379827	1639.64	16.81	-0.000	0.687	-0.000	0.00	-0.00	1.10
B6	640	698	601	628	2916.07	2.99	-0.300	-1.692	0.000	0.00	0.00	-40.66

As a comparison with the obtained lives from the Alternative 2 (B5 and B6), note that the total life for combined bearings can be calculated from the lives of single rows (B1-B2 and B3-B4) as follows:

$$L_{10}[h] = \left[\sum L_{10,i}^{-\frac{10}{9}}\right]^{-\frac{9}{10}}$$

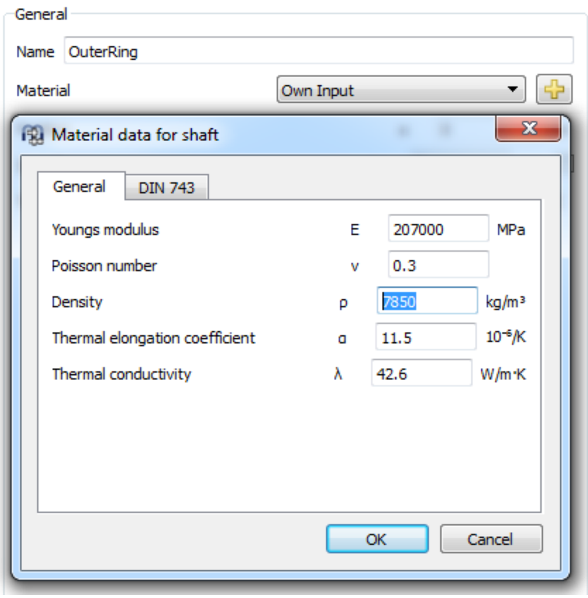
Hence, for the set B1-B2:

$$L_{10,B1B2} = \left[L_{10,B1}^{-\frac{10}{9}} + L_{10,B2}^{-\frac{10}{9}}\right]^{-9/10} = \left[363791^{-\frac{10}{9}} + 110794^{-\frac{10}{9}}\right]^{-9/10} = 89548.5\ h$$

And for the set B3-B4:

$$L_{10,B3B4} = \left[L_{10,B3}^{-\frac{10}{9}} + L_{10,B4}^{-\frac{10}{9}}\right]^{-9/10} = \left[13520^{-\frac{10}{9}} + 634^{-\frac{10}{9}}\right]^{-9/10} = 615.54\ h$$

In terms of modelling, if the weight is considered, it could lead the system of the Alternative 1 to have an additional undesired modal shape in the axial direction because of the shaft 'Outer ring'. In order to avoid this effect, we can set the density of the shaft 'Outer ring' to ρ=0 kg/m3:



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Finally we can see how the pressures of Alternative 2 will have similar values to the ones of Alternative 1. The slight differences in the values are mainly due to the different load distribution that arise when considering the tilting angles at different points in the calculation. Anyway, both alternatives can be independently used with no problems for the same purpose: