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Fine tuning of guitar sounds with changed top plate, back plate and rim geometry using a whole body 3D Finite-Difference model

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Changes of radiated sound from a guitar body are investigated when changing the thickness its parts. The top plate, back plate, fan bracing, and rims are changed in thickness in nine steps each. The model used here is a Finite-Difference model of the whole guitar body and the radiation of the parts are integrated for a virtual microphone position. These sounds are analyzed using a spectral centroid (SC) and a bandwidth spectral centroid (BSC) calculation to make small changes in timbre visible. The guitar body shows nonlinear changes of the brightness of the different guitar parts when applying linear changes to its geometry. The brightness of the parts changed were altered by far the most. Nearly the only exception from this rule was the air which reacted to all changes in a very smooth way. The top and back plate changes lead to 'simple' while still nonlinear changes of the SC. This is not the case when changing the thickness of the fan bracing and the rims. Here more complicated patters occur. Additionally, when considering the different frequency bands the brightness changes are happening, for the top plate a clear cut can be seen when changing from realistic to unrealistic thickness values.

1 Introduction

The sounds of guitars depend mostly upon the precise geometry of the guitar body (Meyer 1983). As the body parts are interacting in a complicated manner it is often hard to determine which influence on the sound a certain change of this geometry may have. The thickness of plates, different fan bracings ect. may cause the system to sound considerable different. From investigations of instrument families (i.e. Bissinger 2002) we know that a linear change of a geometry does not always lead to a linear change of the instrument sounds.

The reasons for the nonlinear changes of timber with linear changes in the instrument geometry depend on many factors, among which are the kind of coupling between the parts, changed resonance behaviour or structure/air coupling. A systematic approach is proposed here using a whole-geometry Finite-Difference model of the classical guitar well studied (Bader 2005a). The advantage here is that all physical parameters, like the Young's modulus of the wood, the precise coupling strength of the different parts or the precise geometry can be kept constant while only changing one parameter of the system.

One aim of guitar and violin builders lately was to make their instruments louder and some appropriate changes are widely accepted and used today. The most important one may be to thin out the top plates of these instruments. Although the overall energy can not increase as this energy is supplied by the player and so stays the same for changed geometries, it is the overall brightness which is increased when thinning these plates. This increase of brightness is psychologically associated with increased loudness. In terms of signal processing of sounds, the spectral centroid as the 'middle' of the spectrum is known to represent the psychological brightness and is therefore used here.

Of course there are many other factors determining the overall character of guitars like the role of the initial transient (Bader 2007). Also other psychoacoustic factors do play their part like spectral denity (Bader 2005b). Still we will restrict our discussion to brightness here because of space restrictions.

In pre-tests the spectral centroid, the brightness showed up to be much more adequate and sensitive to changes in sounds compared to a mere spectrum, where obvious audible timber changes could often only hardly be detected. Our ears can detect very small changes in timber which on the other hand are the decisive factors when judging the character of instruments.

2 Method

The Finite-Difference model of the guitar consists of the guitar strings, top and back plate, ribs, neck and inclosed air. Four different changes of thickness were made.

A) Top plate thickness from 1 mm to 3 mm in .25 mm steps
B) Back plate thickness from 1 mm to 3 mm in .25 mm steps
C) Rim thickness from 1 mm to 5 mm in .5 mm steps
D) Fan bracing thickness from 1 mm to 5 mm in .5 mm steps

All changes have nine steps. A tone was played by plucking the high open e-string and the radiation from the different parts was calculated for 1 second on a virtual microphone position of 1 m before each part. So each step resulted in five sounds and therefore a total of 180 sounds were calculated.

These sounds were Fourier transformed over the range of 20 Hz – 20 kHz and

A) a spectral centroid SC was calculated over the whole frequency range and
B) a bandwidth spectral centroid BSC was calculated using 20 bands of bw = 1 kHz each with centre band frequency of f_m = .5 kHz + n bw, n = 0, 1, 2 .. 19.

The BSC was calculated around f_m like

$$BSC(f_m) = \frac{\sum_{f=f_m-bw/2}^{f=f_m+bw/2} f\,A(f)}{\sum_{f=f_m-bw/2}^{f=f_m+bw/2} A(f)} - f_m \qquad (1).$$

So if in one band the brightness was changed the BSC would detect it and so an association of timber changes to frequency bands is possible. This method showed very valuable when working with instrument builders who could tell in which frequency region a change of sound had happened. It showed up that this change could be very well detected by the BSC even if the changes were very small but audible. Here the pure spectrum was of much less help.

Now, the linear changes of the geometry could directly be plotted versus the SC or the BSC and so a systematic association of the geometrical changes of one part to timber changes of the radiated sounds of all parts separately was possible.

3 Results

The SC and the BSC are calculated for the 180 sounds obtained from the four different changes in nine steps each with five radiated sounds for each step. The SC are presented here first by comparing the radiations for all guitar parts for each of the four changes in Fig. 1. Here, all SCs are normalized in such a way, that all SC of the guitar parts within one change start with the SC of the top plate. This is necessary to make the parts comparable within one plot. Of course the parts have very different overall SCs. Secondly, the changes of SC for each part is compared between the different changing methods shown in Fig. 3.

First it is interesting to see how a thickness change in one part does mainly only change the SC of this part and leaves adjacent parts practically without changes with the inclosed air as exception. A thickness change of the top plate only contributes considerably to the SC of the top plate. This holds for the back plate, too in a much more strict sense. The rim change effects all parts the rims are attached to, the top and back plate and the ribs. The only exception may be found with the fan bracing change which effects the top plate but also the neck. So we can follow, that changing the thickness of guitar parts will mainly only change the SC of the parts themselves. Still the inclosed air is mostly considered by all parts and so the radiation from the sound hole is always effected by changes.

Note that the SC differ from changes of eigenfrequencies of the guitar body which do change, too. The spectrum of a guitar body as a resonance box contains that many eigenmodes, that this spectrum is more or less continues. It also need to be so to avoid ‘dead spots’, notes with much lower amplitude. So not the precise frequencies of the eigenmodes are of interest when judging guitars (and also violins), but the amplitudes of certain spectral regions. These amplitudes constitute the brightness and therefore the changing SC values.

There is also a clear tendency for the top plate to decrease in brightness with increasing thickness of the top plate (thick line in Fig. 1 a)). This is consistent with recent guitar building practice to make the top plate thinner in order to make it louder or brighter respectively. Fig. 2 shows one example in terms of the spectra. Here the top plate sound is plotted for a top plate of 1 mm in a) and of 3 mm in b). As the SC depends on amplitudes, the increase towards lower frequencies in b) compared to a) results in a drop of the SC.

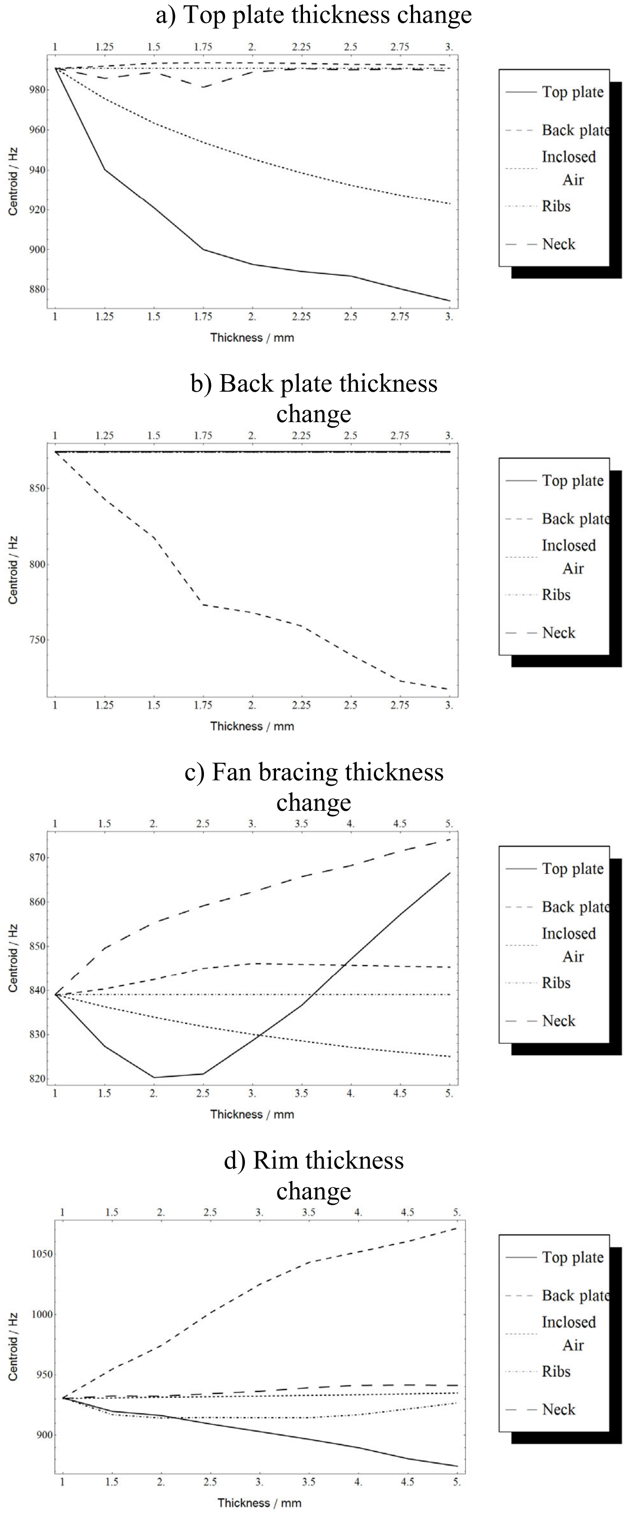


Fig. 1: Spectral Centroid vs. thickness for the four investigated thickness changes of a) top plate, b) back plate, c) fan bracing and d) ribs. The SC is calculated from the radiated sound of the guitar parts top plate, back plate, inclosed air, ribs and neck. Plots are normalized for the top plate SC for 1 mm within each plot.

This also appears with the back plate plotted in Fig. 1 b). Here the SC also drops with the thickness of the plate.

Changes of the top and back plate thickness lead to ‘simple’, although not linear changes. But when we change the thickness of the fan bracing and the rims, much more complicated reaction of parts can be observed. When the rim thickness is increased, as shown in Fig. 1 d), the top and back plate react in an opposite way. The top plate still decreases in the SC values while the back plate increases with increasing rim thickness. If the fan bracing changes, the top plate reaches a minimum SC for a value of about 2 mm dropping from 1mm and increasing the SC again up to 5 mm. The neck strongly reacts here with increasing brightness with thicker fan bracing.

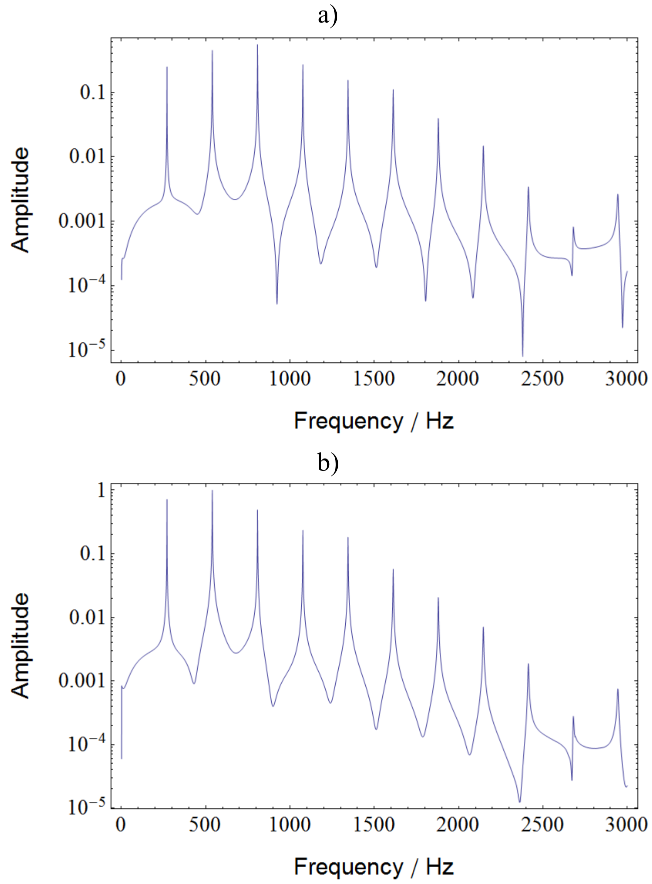
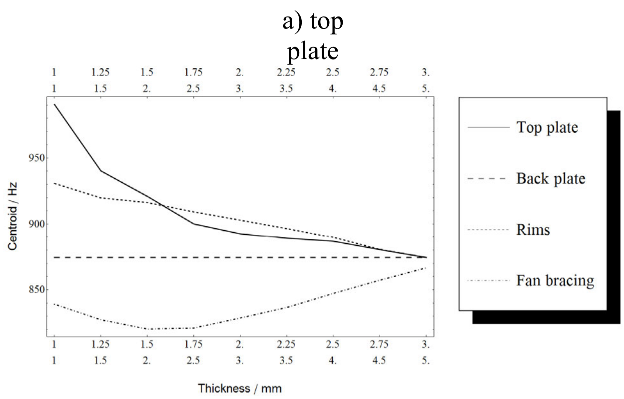


Fig. 2: Comparison of spectra of top plate radiated sounds for the top plate thickness of a) 1 mm and b) 3 mm. A clear downshift towards lower frequencies with the 3 mm sound can be seen which results in a decrease of the spectral centroid for higher thickness.



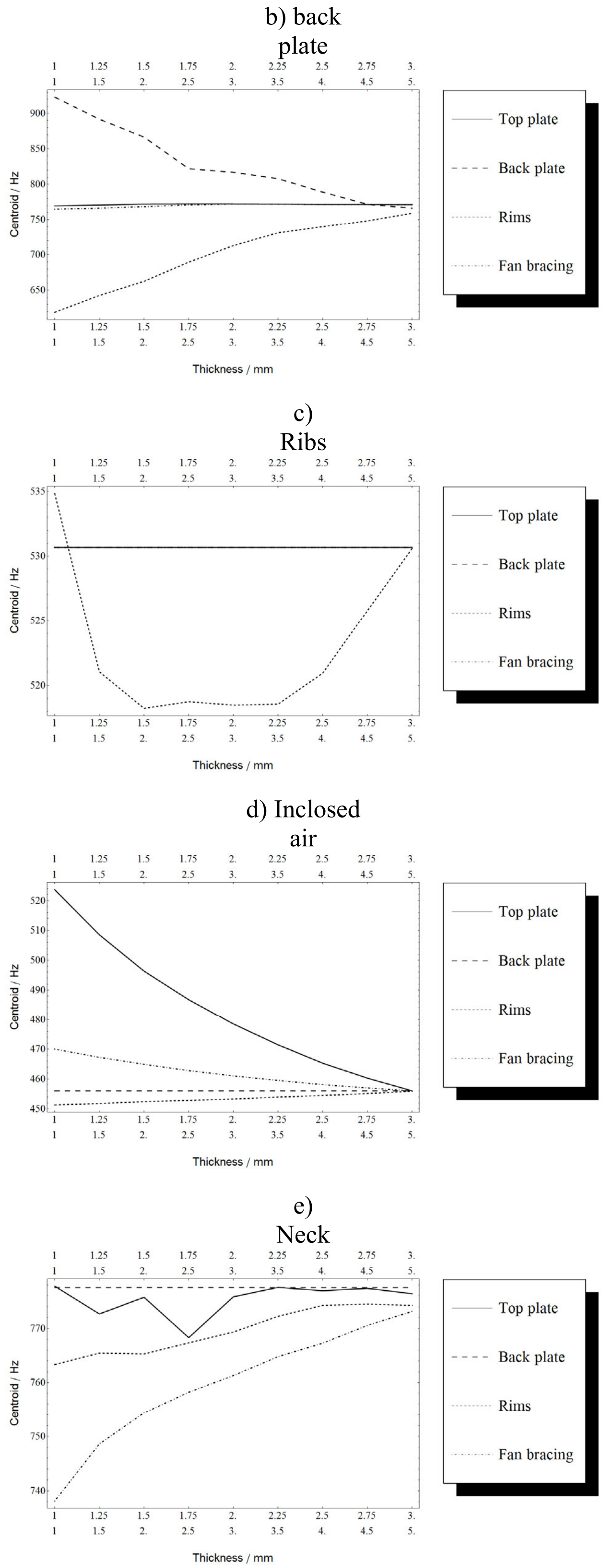


Fig. 3: Spectral Centroid for a) top plate, b) back plate, c) ribs, d) inclosed air and e) neck radiated sound changes comparing different thickness change parts.

The inclosed air follows the top plate much more than the back plate. It is not concerned by a change of the rims and goes its own way when changing the fan bracing.

The ribs do not show much tendency to change in brightness at all, only when changing the rims, it shows a nonlinear change but much smaller than that of the top or back plate.

When interested in changing the brightness of the guitar part radiation, the method one would need to apply to make such changes is important. Fig. 3 shows the sound changes of one guitar part each comparing the different thickness change methods.

When one wants to change the brightness of the top plate, it can be decreased by making it thicker or by thickening the rims. Changing the fan bracing may in- or decrease the SC.

The back plate can be manipulated in both directions by either changing the thickness of the back plate itself or by changing the thickness of the rims leading to opposite results.

The sound of the ribs is not much adjustable by any method, a bit by changing the rim thickness. It is supposed here that the change of the thickness of the rims themselves will lead to bigger changes which was not tested yet.

The inclosed air sound is very smoothly decreasing with top plate changes and a bit with changing the fan bracing to thicker values. It may slightly be increased here by thickening the rims or the back plate.

The neck is again not much changeable in brightness, a bit by rim changes and much stronger by changing the fan bracing.

The main results may be summerized as follows.

a) Thickness changes of one part mainly only results in brightness changes of this part.
b) The rims have a great influence on top and back plate radiated brightness in opposite directions and upon ribs.
c) Increasing the fan bracing thickness first de- and then increase top plate brightness with a minimum SC at 2 mm thickness.
d) Increasing the fan bracing thickness leads to a high increase of the brightness of the neck.

Fig. 4 shows the BSC for the thickness changes of the top plate when changing a) the top plate, b) the fan bracing and c) the rims. One can clearly determine regions of much change and others with less influence on the overall SC.

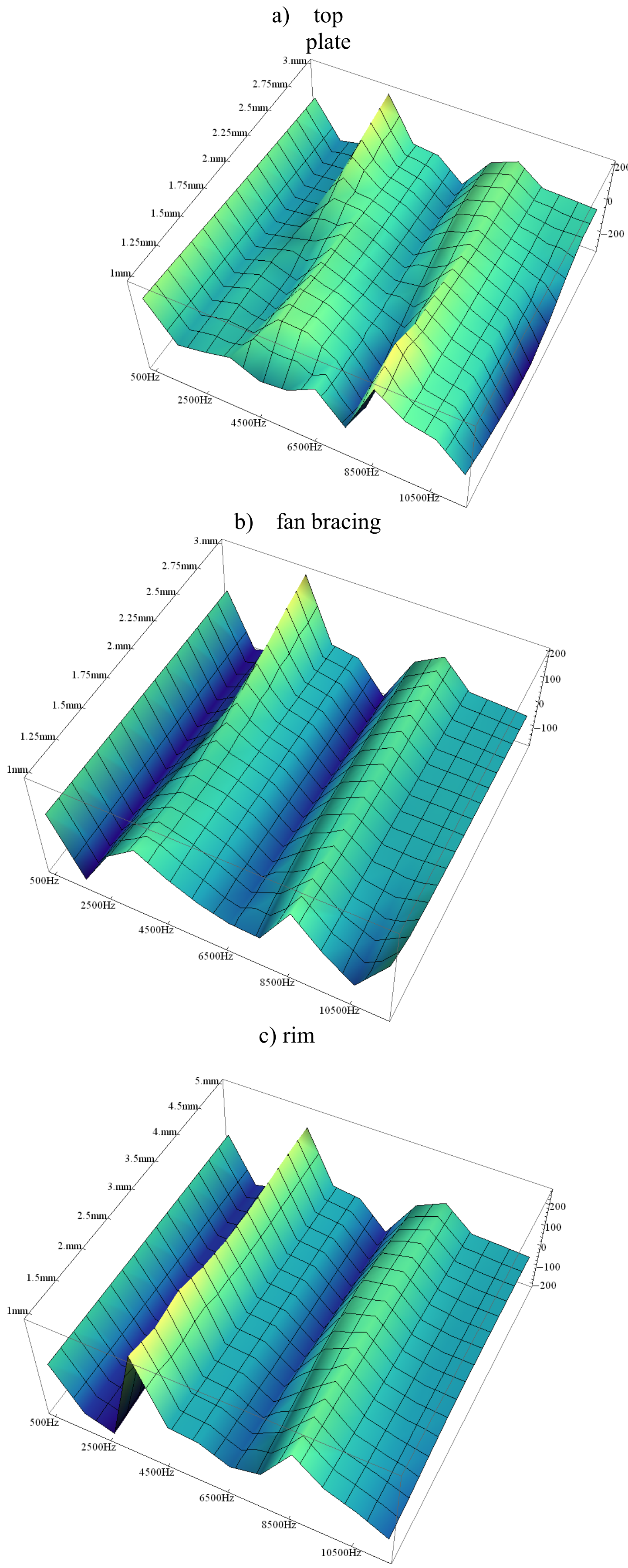


Fig. 4: BSC of the top plate sound for thickness changes of a) top plate, b) fan bracing, and c) rim.

The regions around 3 kHz are only prominent for the fan bracing and rim sounds. The top plate sound changes brightness suddenly with a top plate thickness of 2 mm which also holds for the fan bracing brightness around 3 kHz. Note that the BSC does not care about the overall amplitude of the frequency regions. So a change in one region in the plot may have more or less influence on the overall SC because of its overall amplitude range. This is not shown in the BSC plots where we do concentrate on the changes themselves.

It is interesting to see in these BSC plots, that when values are changing from realistic to unrealistic for guitars (i.e. a top plate thickness of less than 2 mm is practically impossible) the BSC plots show a clear cut and change their behaviour considerably. Also the tones start to sound unrealistic beyond these geometrically unrealistic regions. This could also be found with violins (paper in preparation), where also listening tests showed a clear cut between realistic and unrealistic geometries also when only dealing with the sounds alone.

4 Conclusions

Linear changes in the geometry of guitars lead to nonlinear changes of the sounding brightness of guitars. These changes show a cut when changing from realistic to unrealistic geometries within the spectral centroid bands. This is mostly not true for the overall spectral centroid. Also when changing one guitar part the SC value is most strongly changed for that part only. This does not hold for the inclosed air and so for the radiation from the sound whole. The changes of the fan bracing and the rims show very different changes in the SC values compared to overall thickness changes of the top and back plate. Much more complicated behaviour is found here. So i.e. the neck shows a considerable increase of brightness with changes of the fan bracing, much more than the top plate is influenced by this change. The overall tendency of guitars to sound brighter when the top or back plate are decreased in thickness as often used by instrument builders nowadays clearly shows up.

The changes of brightness as calculated by the model are quite complicated. The physical reasons for these changes are changes in amplitude of the resonating guitar body with thickness changes of different parts. Further investigations need to be done to determine the impedance of the guitar body when these changes are applied. Here also damping need to be taken into consideration. With an analytical solution, the Timoshenko formulation of the plate could be used as it also considers the plate thickness.

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