Mastering chaos

The butterfly and the bearing

Stable or not, the motion of the cage of a ball bearing is chaotic[1].

A well known example of a chaotic system is the numerical weather forecasting. Meteorologists have a set of sophisticated instruments to their disposal (satellites for Earth observations, for example), which allow them to visualize the weather at present (temperature, atmospheric pressure, etc.). Based on that and using comprehensive mathematical models, those scientists are capable to reliably predict the weather two or three days in advance. Unfortunately, as everybody knows, beyond such short period of time, each attempt to correctly forecast is illusory.

Is it due to a lack of reliability regarding the developed models? Are the computers not powerful enough to tackle the difficult tasks they are facing? None of that. The unpredictability is intrinsic to the weather forecasting. To be clear, no matter the quality and the precision of the physical laws incorporated within the models, it is mathematically impossible to state how the weather will evolve in the medium or long term. This statement comes from the nature of the mathematical system of equations governing the meteorological phenomena.

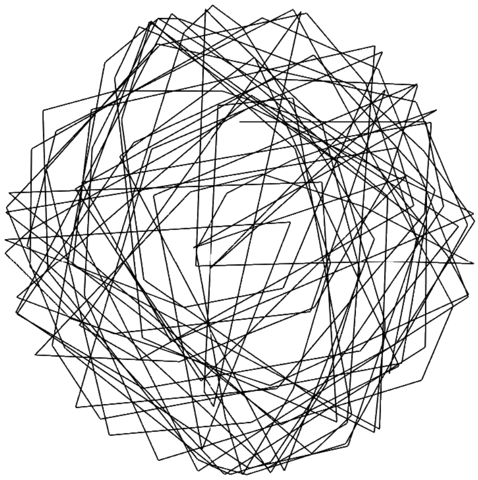
Hence, in that case, a very small variation of the initial conditions may imply huge changes after a certain amount of time. Because of this, every attempt of weather forecasting by means of mathematical models is impossible. This is the so-called « Butterfly Effect » pronounced by the meteorologist Edward Lorenz, who originally presented it trough the rhetorical question: « Does the flap of a butterfly's wings in Brazil set off a tornado in Texas? » In other words, the sensitivity of the system is such that a small variation in the pressure induced by a single bug could theoretically lead to the formation of a tornado or, conversely, prevent its appearance.

To summarize, a dynamical system can be considered as chaotic if it meets two criteria. The first one is a particularly high sensitivity to the initial conditions. The second criterion is a lack of periodicity in the evolution of the system's variables over time, which gives the impression of a random process.

The motion of a ball bearing cage is chaotic. Indeed, it is not possible to predict where the cage will be located within the bearing, even a few tenths of a second after the start of the bearing rotation. As for the weather forecast, a mathematical modeling, even if it is extremely good, cannot pretend to compute the actual trajectory of the cage.

In order to visualize this statement, let us imagine that we perfectly know the position and the speed of a bearing cage at a given time. The trajectory that the cage would have within the bearing during the first two seconds after the start is represented hereafter.

[1] See our article *What is cage instability?*

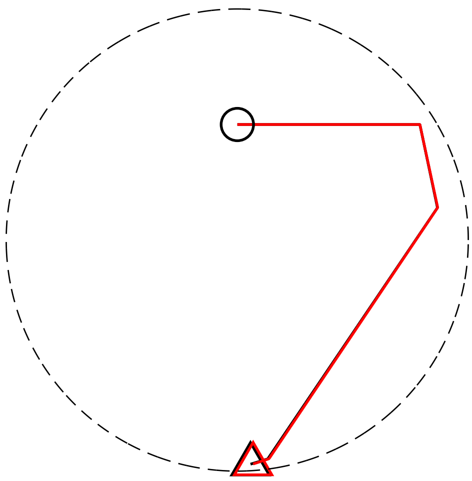


Typical trajectory of the center of a bearing cage

As we can see, the curve presents a muddled behavior.

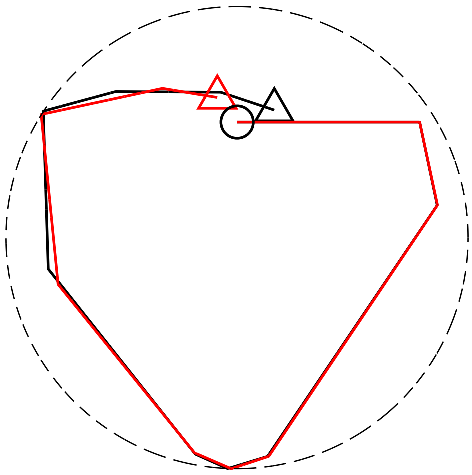
What would happen if we decide to study the motion of this cage placed in identical conditions, but this time with a difference of one micron in the starting position, so basically nothing?

The figure hereafter gives a representation of the first five hundredths of a second of both trajectories. The black circle represents the starting point. This one is thus similar in both cases, down to the micron. The red and black triangles are the current position of the center of gravity of the cage for both configurations. The dotted circle is a representation of the cage clearance (0.2 mm in the present case).



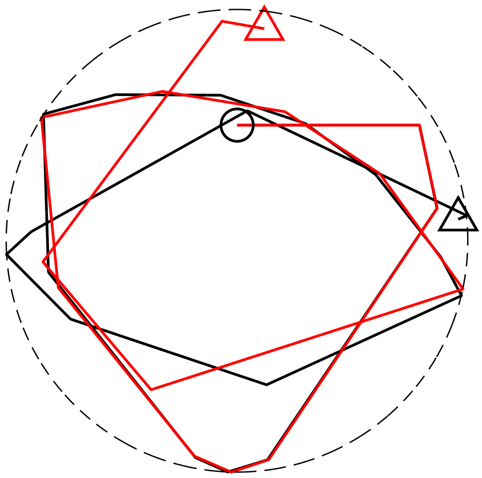
Comparison of both trajectories of the two cages after five hundredths of a second

As we can see, the two trajectories coincide almost perfectly at the beginning of the motion. Although, one may note that they seem to diverge after a while. That is confirmed by the rest of the motion, as it can be seen on the next figure.



Comparison of both trajectories of the two cages
after one tenth of a second

The road to chaos is initiated. No need to pursue the study of the trajectories for too long to understand that point. Indeed, after only two tenths of a second, both curves diverge and keep evolving in two completely different and anarchic ways. That is shown in the figure below.



Comparison of both trajectories of the two cages
after two tenths of a second

Thus, only a few fractions of a second were necessary for the butterfly with a wingspan of one micron to entirely transform the course of events.

The bearing and the tornado

The weather is likely to display unstable conditions, like thunderstorms. The motion of the ball bearing cage follows the same logic. If some conditions are met, the energy level of the cage suddenly increases and we face cage instability.

Because of the chaotic nature of the cage motion, it is impossible to predict when such an instability will occur. In the same way, no meteorologists, no matter their abilities, would be able to forecast *where* and *when* the lightning will strike.

So, does it mean that information cannot be extracted from a chaotic model? The answer is no, fortunately.

The mechanism of thunderstorm formation is well known. Scientific developments allowed to determine the origin of such meteorological instabilities through observations and mathematical models of the governing phenomena. As a matter of fact, huge amounts of hot air with moisture at ground level, combined with dry and cool air at high altitude are the basic ingredients of the occurrence of lightenings. As a result, specialists perfectly know *why* a thunderstorm starts.

APO-GEE used the same approach to establish which elements are necessary for the start of a dynamic cage instability. The purpose is not to predict *where* and *when* a cage instability will appear but to explain *why* it will. Nevertheless, the comparison with the Earth science stops here. Because, contrary to meteorologists, once the identification of the source of cage instability is performed, APO-GEE is capable to efficiently act on the bearing conception in order to counteract the deleterious phenomenon. Any kind of prediction then becomes useless: the cage will be stable in every circumstance.

Could you imagine a world without thunderstorms? We did that at our level.

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APO-GEE ENGINEERING SRL has solved the CAGE INSTABILITY PROBLEM, to which no fully satisfactory response has been possible for more than 50 years (patent pending EP22191261). See www.apo-gee.tech.