GALILEO AND THE UNIVERSALITY OF FREE FALL

D. Bramanti, G. Catastini, A.M. Nobili, E. Polacco, E. Rossi, R. Vergara Caffarelli
Università di Pisa, Italia

Extended Abstract* Galileo's formulation of what has become known as the *Equivalence Principle*, according to which all bodies fall with the same acceleration regardless of their mass and composition, was first published in 1638. It appeared in his *Discorsi e Dimostrazioni Matematiche intorno a due Nuove Scienze Attinenti alla Mecanica e i Movimenti Locali*, which was published outside Italy (in Leiden), some years after its completion due to Galileo's prosecution by the Church of Rome. Galileo was 74 *years* old, already blind and under house arrest. Indeed, the *Discorsi* are based on much earlier work, going back almost 40 *years* to the time when he was a lecturer at the University of Pisa or had just moved to Padova. By dropping different masses in media much denser than air Galileo came to the conclusion that all bodies fall with the same acceleration, while any observed difference is due to the different resistance of the medium. The statement in the *Discorsi* is quite remarkable (*Le Opere, Vol VIII, p. 116*) *... veduto, dico, questo, cascai in opinione che se si levasse totalmente la resistenza del mezzo, tutte le materie descenderebbero con eguali velocità* (*... having seen this I became convinced that, were the resistance of the medium eliminated, all materials would fall with the same speed*). Galileo was also aware of the difficulty in proving this statement by dropping masses from a height. As he clearly argues in the *Discorsi* (*Le Opere, Vol VIII, p. 128*), from a big height the accumulated effect of air resistance is too large to allow reaching a reliable conclusion, while from a small one any difference is too small to appreciate. Most probably Galileo was not able to calculate precisely the effect of air resistance, but he certainly knew that it was much smaller if the velocity of the body was small. He therefore conducted experiments with bodies falling on inclined planes and, eventually, with pendula. The pendula experiments are described very clearly in the *Discorsi* (*Le Opere, Vol VIII, pp. 128-129*) (already mentioned in 1602 in a letter to G. Dal Monte, *Le Opere, Vol X, pp. 97-100*), and it is apparent that they allowed Galileo to reach an accurate conclusion. Instead, he is famous worldwide for the tower experiments, which are often brought into the discussion in the *Discorsi* when arguing with Aristotle. This we believe he did because –unlike the pendula– they allow to describe the universality of free fall in a very straightforward manner. We have compared modern calculations taking into account all non gravitational effects with mass dropping experiments that we have performed from the Tower of Pisa using a rather accurate (although quite simple) mass release system. Unless the effect of air resistance is compensated by an appropriate choice of density and dimension of the bodies, they do actually reach the ground at quite different times. The mass dropping experiments mentioned by Galileo in the *Discorsi* would in fact have given different results from what he mentions. However, the younger scholar Vincenzo Renieri describes in a letter to Galileo in 1641 his own experiments from the Leaning Tower of Pisa, and esplicitly mentions it (*Le Opere, Vol XVIII, pp. 305-6*). We find that the differences observed by Renieri are consistent with the effect of air resistance. We conclude that while Galileo formulated very clearly the universality of free fall and proved it with pendula many decades before Newton, he probably never dropped masses from the Tower of Pisa.

---

* *Paper to be submitted*