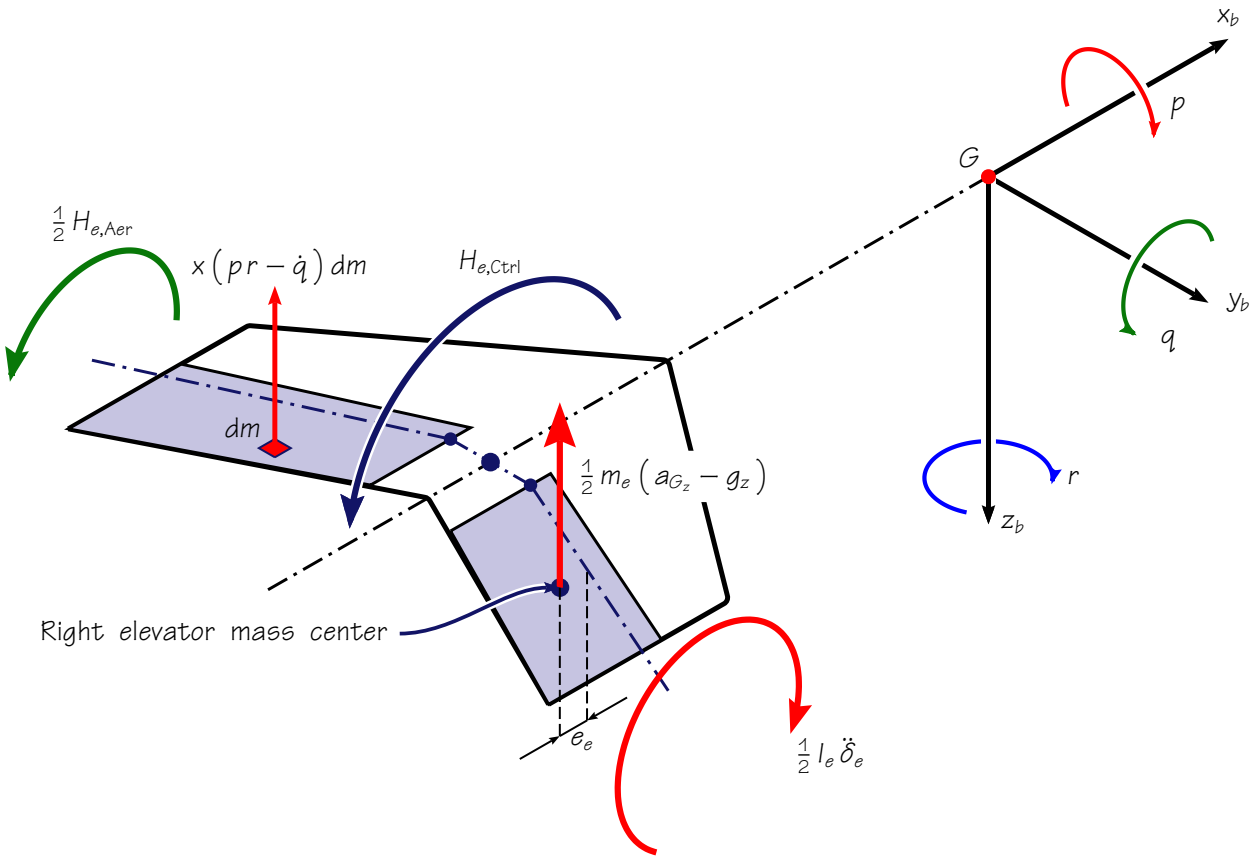

Figure 14. Schematic of the actions acting on the elevator

When a force feedback system is matched with the solver of aircraft motion equations, the actions on the aerodynamic control surfaces—which are directly transferred to the cockpit controls as column and pedal *loads* in a reversible system—have to be computed from the known aircraft state at each simulated time step. Stick and pedal loads are synthesized with a given frequency, typically higher than the simulation frequency, and properly reproduced (see Rolfe[8] or Lee[9] for a general discussion). This is mainly due to the presence of the pilot in the simulation loop and to the fact that the action of pilot on the primary controls have to be accurately measured.

In our control loading module the simulation of the aerodynamic control surfaces (ailerons, elevator, rudder) has been extended, with respect to the functionalities of FlightGear and JSBSim, and implemented in a dedicated piece of software (see *ForceGear* in Figure 20). The evaluation of the aerodynamic and inertial actions on the aerodynamic control surfaces is one of the main tasks of this code. It solves the equations of motion (1)-(2)-(3) between two successive FlightGear time steps. The external actions on each aerosurface are evaluated in what is also referred to as the "inner" integration loop. FlightGear's job is then called the "outer" integration loop.

At this point we recall that the *stick-free* conditions are those particular situations in which the pilot actions on the cockpit controls are null and the aerodynamic control surfaces are free to float under the effect of external actions. In stick-free condition terms like $F_{e,\mathrm{C}}$ in equation (2) are zero.

Aerosurface external actions depend: (i) on the aircraft motion and acceleration, and (ii) on the characteristics of the mechanical linkage between the control column located in the cockpit and the tail plane moving parts. In all cases the excursions time rates are evaluated and used by the force feedback module to reproduce friction-dependent effects.

In the general case of simulated stick-free flight of a general aviation aircraft with reversible controls the angular deflections of aerodynamic surfaces represent a set of additional state variables. Then the additional unknown time histories of angular excursions $\delta_a(t)$ (right aileron), $\delta_e(t)$ (elevator or stabilator), $\delta_r(t)$ (rudder) have to be determined by the control surface model.