

Needle-Free Drug Injections

By Y. Liu, and M.A.F. Kendall, Department of Engineering Science, University of Oxford, Oxford, UK

A novel, needle-less, powdered drug delivery system is currently being developed. It makes use of biolistics technology, where tiny particles are injected through cell walls by a high-powered gun. The technology provides a unique capability; it effectively delivers vaccines in micro-particle form through the skin, into an epidermal layer where Langerhans cells reside. By targeting these cells, an optimal immune response can be elicited, potentially decreasing both the risk of disease and cost of protection. In the gun, high-pressure helium gas is stored in a micro-cylinder, and the powdered vaccine is stored in a cassette. The gun accelerates the vaccine particles into human skin with a transient supersonic jet. To do this, the particles must be delivered with a narrow and controllable impact velocity range, and a wide, yet uniform spatial distribution.

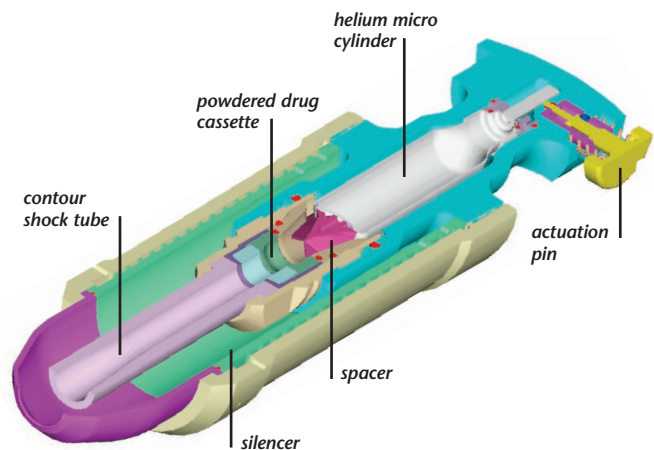
Ideally, the bulk of the particle cloud should be accelerated in the quasi-steady supersonic flow (QSSF) regime. Proper choice of system geometry, gas species, and operating conditions can ensure that this condition is met. Practical constraints limit the device length and the duration of QSSF, when the particles are to be entrained. To better understand the delivery mechanism and biological interaction, the effects of these important parameters need to be identified and understood.

FLUENT software offers comprehensive capabilities to model the biolistics system, from the transient gas and particle dynamics to interactions with the skin target. The species transport equations together with the standard k- ϵ turbulence model are used to solve for the multi-species gas phase flow. The coupled explicit solver is used to capture the main features of the unsteady motion of the shock wave process. An overall second order accuracy is satisfied both spatially and temporally. The particle trajectory equations, in conjunction with a drag correlation and inter-phase heat exchange, are advanced in time with the gas flow simulation. The drag correlations proposed by Igra & Takayama (1993), which consider unsteady effects and cover a wide range of Reynolds numbers (200 to 101,000), are implemented through user-defined functions (UDFs).

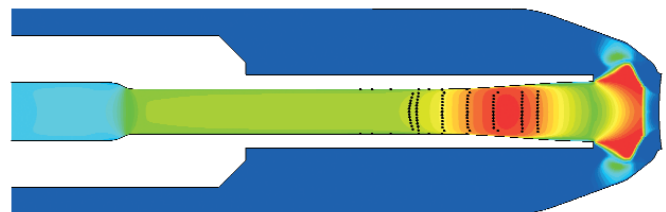
Through the modeling efforts, the FLUENT simulations have allowed for the evaluation of key parameters, the visualization of different designs, and the gathering of new insights into the biolistics system. Simulations of the whole prototype biolistics system, as well as of the key components, have shown an excellent agreement with the static pressure measurements, Pitot probe survey, and images made using Doppler global velocimetry (DGV) and particle image velocimetry (PIV).^{1,2} A space-time diagram that shows different gas flow regimes and particle cloud trajectories can be used to illustrate the performance of the prototype. The diagram demonstrates that the particles are accelerated to the nozzle exit, avoiding the starting process¹ and the reflected expansion wave, and thereby remaining in the QSSF regime, as desired. ■

references:

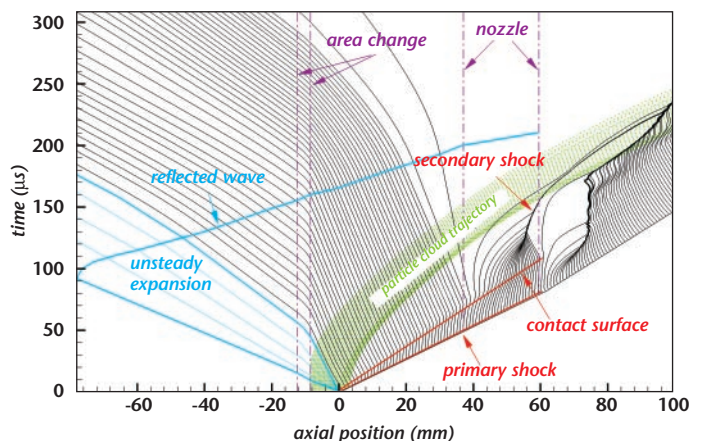
- 1 M.A.F. Kendall, *The Delivery of Particulate Vaccines and Drugs to Human Skin with a Practical, Hand-held Shock Tube-based System*, Shock Waves Journal, 12(1), pp.22-30, 2002.
- 2 Y. Liu, M.A.F. Kendall, N.K. Truong, and B.J. Bellhouse, *Numerical and Experimental Analysis of a High Speed Needle-free Powdered Vaccines Delivery Device*, AIAA-2002-2807, Proc. 20th AIAA Applied Aerodynamics Conference, St. Louis, MO, USA, 2002.



A schematic of a prototype biolistics system, configured for clinical use¹



Instantaneous contour plot of the gas velocity and particle trajectories for a silenced configuration, taken 120 μ s after diaphragm rupture²



The key gas flow regimes and particle cloud trajectories of the prototype biolistics system are shown together in the calculated space-time (x-t) diagram²