Group 113

Launching Blood Droplets up to 50m/s

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Abstract

To validate a model used by the Netherlands Forensics Institute (NFI), used to analyze and determine blood droplet speed and point of origin at crime scenes, a catapult was designed and built. The catapult can launch a blood drop up to a horizontal velocity of 50 m/s. Tests at the NFI[1] showed the device capable of launching blood at 15m/s when the spring was only partially loaded. Improvements to the torsion spring orientation and release mechanism were shown to be needed to reach the desired 50 m/s horizontal velocity.

1 Introduction

The Netherlands Forensics institute has developed a model that determines the point of origin and speed of a blood droplet with greater accuracy than before by taking into account the effects of gravity on the blood drop[2]. This improved accuracy could help investigators more reliably determine what happened at a crime scene[2].
The NFI has managed to verify their model up to speeds of 6m/s[3]. This paper details the building of a catapult, testing the speed, diameter and reliability of the blood droplets launched from it, and an initial perfunctory comparison between the tests and the NFI's model's predictions.

2 Theory and Design

There were two major things to consider when working with blood; First was dealing with the fact that the stable drop diameter, before it breaks up into smaller droplets due to drag forces overcoming the droplet's own surface tension[4] was dependent on the maximum speed the drop would attain, this happens when the Weber number is equal to 13[5]. This relation is characterized by equation 1.

$$d_{max}(v) = \frac{We * \sigma}{v^2 * \rho} \tag{1}$$

Where $d_{max}(v)$ is the maximum stable diameter of the blood drop as a function of it's velocity, We is the Weber number of the blood drop, σ is the surface tension of blood, and ρ is the density of blood.
The second consideration was fluid sticking[6]. The non-deterministic behavior of a fluid on a surface during acceleration meant a number of materials needed to be considered[1] and tested for their hydrophobic properties. The hemophilic nature of many common building materials[6] meant a polymer was most likely to allow the blood to launch from the device without the sticking behavior affecting forcing the desired flight trajectory downwards.

From the potential concepts[1] a catapult was chosen. It stores energy by means of a torsion spring (1 b), which is winched by means of a ratchet (1 a) and held by a steel cable. After the first test session at the NFI, the catapult was improved with a reliable and safe release mechanism, an acrylic enclosure to ensure the steel cables can't harm the user when they are released, and with a new container to place the fluid in. Later tests at the TU Delft were performed with a 1:1 water-glycerol mixture[7] because

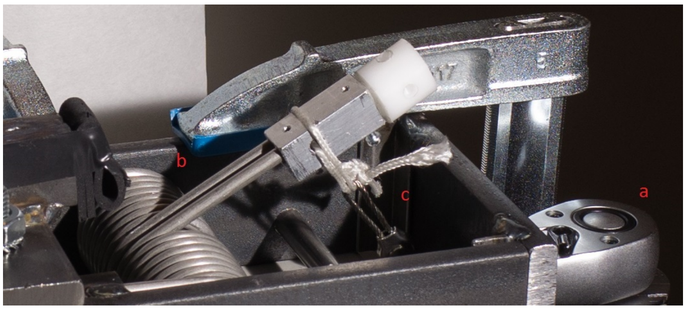

Figure 1: The first catapult prototype during testing at the NFI. a) denotes the ratchet mechanism that allows for pulling the arm back. b) denotes the torsion spring with the arm and POM bucket, which holds the blood, affixed on top. c) denotes the release mechanism; in this case the manual cutting of the nylon rope

the density, surface tension and viscosity of the mixture at room temperature are comparable to blood at 37.5°C.

3 Tests

3.1 Proof of Concept Test at NFI

On December 15th a series of tests were performed at the NFI, these tests were used to test the prototype's performance under conditions that it would be used by the NFI. The tests also brought into focus some shortcomings that had not been foreseen in the design phase; the nylon rope rubbed against the steel frame of the catapult, resulting in wear and premature failure, the nylon will be replaced by steel cables. The arm of the catapult was made lightweight with aluminum, but the impact proved greater than anticipated so a stronger, steel version should be made for the next prototype. The release of the catapult arm was done by cutting the rope that held it in place, this meant nonsustainable and nonreproducible results so this was replaced by a release latch.
Finally the bucket at the end of the arm that held the fluid released the fluid in a chaotic manner[1].

3.2 Validation Tests at TU Delft

The test at the TU Delft served to validate the changes made to the prototype and with a Photron FASTCAM-APX RS high-speed camera with a Nikon AF Micro-Nikkor 105mm f/2.8D lens, the fluid behavior was documented. Three sets of four tests were performed, each test had the arm pulled back to a certain angle; 50, 60 and 70 degrees. The main emphasis of the tests was the fluid's launch angle and speed, particularly if repeated tests with the same initial conditions provided similar results.

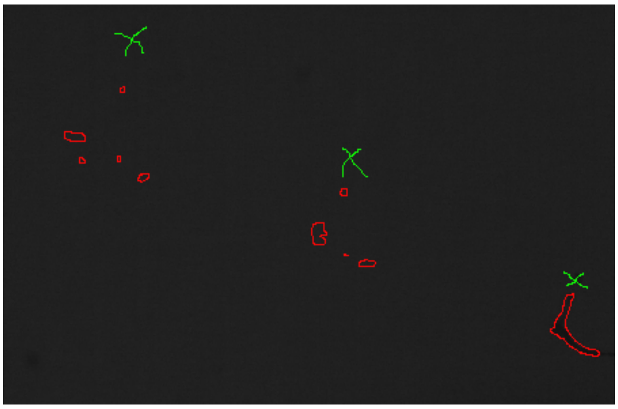

Figure 2: An excerpt from a processed test. The highspeed footage of a test (this was test 3 of pullback angle $50\,\mathrm{deg}$, for more information and processing see [1]), here the green x marks the centroid of a droplet being tracked, the red areas show the remaining fluid. This image has 3 test frames superimposed on it, each test frame was taken 1ms after the previous one.

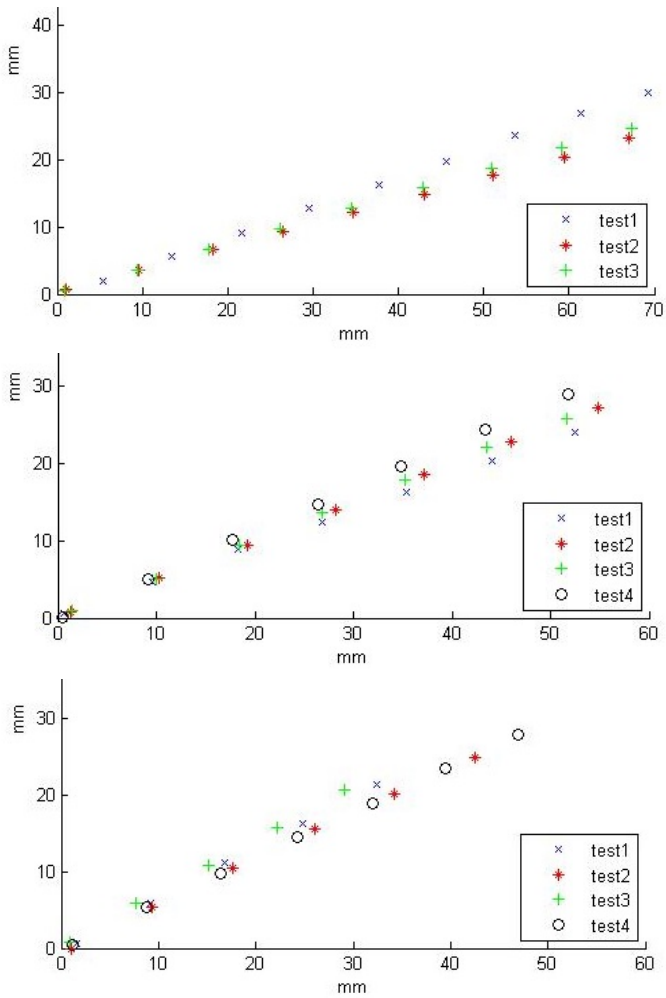

Figure 3: The results of testing of pulling the catapult arm back to top) $50\,\mathrm{deg}$, middle) $60\,\mathrm{deg}$ and bottom) $70\,\mathrm{deg}$.

3.3 Results

The results of the series of tests with pullback angles $50\,\mathrm{deg}$, $60\,\mathrm{deg}$ and $70\,\mathrm{deg}$ are plotted in figure 3. Each datapoint is taken at 1ms intervals. The axes and origin have been moved to indicate the droplet's behavior when taken from a common origin.

4 Discussion and Improvements

The results show a consistent and predictable trajectory for the fluid drops. Unfortunately the fluid leaves the container before it reaches its maximum speed, meaning that for the blood drops to reach the required 50m/s, the catapult arm needs to faster still. The results show a predictable droplet trajectory for the various pullback angles. However the container shape does seem to enable the premature ejection of the fluid. This has the advantage of forming a drop that is easily tracked with the highspeed camera, but the disadvantage that the fluid does not absorb the full range of energie being unleashed by the spring. Compared to the previous container for the fluid, this is an upgrade, but there is still room for improvement and the sizing and shaping of a better container would be the next logical step to focus on.

The prototype can already be used to launch blood drops at speeds ranging between 8 and 12 m/s, and with a stronger spring this can be increased up to 20m/s [1]. Furthermore a container that retains the fluid for longer also means an increase in speed range by virtue of transferring a larger portion of the spring energy to the fluid. The catapult's modular design does allow for interchangeability between parts such as springs, container and arm.

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