Clarifying Recent Controversy Regarding Lussi Jump Technique

As author, I originally wrote this in response to 2015 discussions in *PS Magazine* regarding Gustave Lussi's jump techniques. I am well-versed in the dynamics of rotational motion, jump on skates myself, and can offer an understanding of the specific dynamics of Lussi jumps. I have a Ph.D in Aeronautics and Astronautics from MIT, have spent most of my engineering career in the analysis of spacecraft dynamics and control for Department of Defense and NASA projects, and have published extensively in several professional journals within the aerospace community. The dynamics of spacecraft in the vacuum of space is similar to the nearly frictionless environment of skates on ice and rotating skaters in the air. I have also held positions such as vice president of a publicly traded, billion dollar technology investment company.

The discussions in question originated with an article entitled "Using Basic Physics to Avoid Injuries," by Cecily Morrow, published in the September/October 2015 issue. The article advocated the use of Gustave Lussi's jump techniques to help avoid injuries and was followed by rebuttals in an Editor's Note published in the November/December 2015 issue. When I submitted my original physics based analysis of the article and Editor's Note to the PSA, they declined to publish it. The material below presents the key physical aspects of skating jumps that differentiate Lussi delayed-rotation jumps from other jumps that rotate at take-off, "rotation first" jumps.

Let's look at two important components of a jump performed by a human body on a pair of skates on ice: (1) the torque generation prior to take-off and (2) the initiation of fast rotation after take-off. In all jumps, the purpose of torque generation is to create a large angular momentum at take-off. The larger the angular momentum, the greater the potential for fast rotations in the air. Initiation of fast rotations in the air is carried out through the decrease in the moment of inertia around the spin axis, by bringing body parts closer to the body axis. The greater the decrease in moment of inertia, the greater the acceleration of rotational movement. While each component focuses on a different aspect of the jump, they are intricately linked to each other.

One can employ different strategies for these two components of the jump. The choice of strategy for torque generation intricately affects the body actions available for initiating fast rotation. Using the triple Axel jump as an example, in the "rotation first" or rotation at take-off approach, the jump take-off is skated on a circle and torque is generated by muscle actions associated with the simultaneous curved edge take-off and swing of the free hip and side forward, up and around in the general direction of the circle. This torque generation is accompanied by pulling in of arms and bringing the free leg into a bent-knee posture to create an initial rotation, often occurring while the blade is still in contact with the ice. This allows the rotations to begin as the skater is taking off the ice in the triple Axel (often to the extent of having pre-rotation prior to take-off), but at the expense of a limited amount of additional rotation acceleration once airborne. In contrast, in the Lussi delayed-rotation triple Axel approach, the skater steps on a tangent to the circle, and torque is generated by muscle actions associated with the simultaneous straighter edge to toe take-off, such that the skating leg pushes the whole body forward, up and out at a 45 degree angle to the take-off line, the free side passing slightly forward of the pushing leg, and the body parts, including arms and legs, fully outstretch upon take-off. This delayed-rotation jump strategy results in a large moment of inertia immediately after becoming airborne, allowing a maximal reduction of moment of inertia when body parts are pulled closer to the body axis, creating a larger acceleration of rotation than possible with the "rotation first" approach.

Referring to Morrow's description, the skater being "outstretched in mid-air" can thus be seen as a key aspect of Lussi's delayed-rotation jump strategy, from a dynamics point of view. Many figure skating critics and even researchers fail to recognize that there are multiple jump strategies. Many academic articles, from the 1980s to present, focus on measuring some dynamic variables, such as angular velocity, moments of inertia, and angular momentum, at various points along the jump process, hoping to glean some insight into how accomplished skaters differ from less capable skaters, and how jumps with different numbers of rotations differ from each other. The majority of articles assume that there is only one jump strategy, namely "rotation first". Could Cabell's comments suffer from the same faulty assumption?

Let's turn to Cabell's statements (in quotes). My responses follow each of Cabell's quotes:

- "It is absolutely necessary to take off from a curve. The skater cannot take off from a straight line and rotate. That is not possible if an angular momentum is to be created." It is the torque, generated by the opposing motions of both sides of the body, that creates the necessary angular momentum upon take-off. As long as the skater is able to generate opposing forces using both sides of the body, a torque is created, regardless of curve or no curve.

- "A torque is necessary while a blade is in contact with ice. That is the only way to create an angular momentum which carries through the flight. That is how a necessary rotation is created." Morrow's original article does not question or argue against this fact.

- "No need to focus on the arms and free leg positions during the take-off time, focus on the skater's blade, ankle, hips, and shoulders." This statement runs counter even to the "rotation first" jump strategy where skaters do pay close attention to arms and free leg positions as described in the "rotation-first" triple Axel take-off above.

- "That will determine the quality of the take off and the jump itself." This statement is consistent with many researchers' approach in analyzing skaters' jumps. However, it ignores the important fact that Cabell is comparing apples to oranges when applying this viewpoint across different jump strategies. A Lussi delayed-rotation jump is not just a "rotation first" jump with the arms and leg extended at take-off.

- "*[The unhinging of the leg and opening the arms that complete the last three-quarters of the jump rotation, preparing the skater for a clean landing with increased speed (in the Lussi method)]…* is not possible in today's triple and quadruple jumps. Simply there is no air flight time for that. The skater tries to maximize the air time and land in the necessary closed position in order to complete the rotation. In quadruple jumps, a skater needs to complete two rotations before the apex of the jump and two rotations after. No time for a delay of rotation." Within the Lussi delayed-rotation jump strategy, more air time and faster rotation are achieved than in rotation first jumps. The following are two reasons why. (1) The separation of the take-off thrust from the initiation of fast rotation allows the skater to jump higher and farther because the push-off leg can focus solely on pushing forward and up, maximizing forward and upward momentum. In addition, the push-off leg does not need to overcome the centripetal force from skating on a curve that the rotation-first skater must contend with. (2) The initiation of fast rotation occurs very rapidly because the explosive stretching of the arms and legs to their limit of motion causes a powerful recoil inwards into the closed rotation position due to the body's

elastic response. Indeed, in baseball pitching, elastic energy has been proven to create more velocity than simply contracting the muscles in the arm to generate velocity[1], enabling pitchers to achieve pitches of 90+ mph. These factors contribute to the ability of skaters using the Lussi delayed-rotation method to achieve triples and quad rotation jumps more efficiently.

As far as I can tell, after careful study of jump techniques, there are no physics-based deficiencies of the Lussi delayed-rotation jump method for use in accomplishing triples or quads. In fact, there are many desirable features of the jump technique, including greater air time, greater height, distance, and flow out of the jumps. At the 2016 PSA Convention, Scott Hamilton and other presenters emphasized that there are several ways to perform multi-rotation jumps. Indeed, let's allow all methods to be developed and tested.

[1] Sanzeri, Nick, CSB: Pitching Elasticity (Keys to Velocity) Sanzeri Baseball LLC, http://www.sanzeribaseball.com/articles/csb-pitching-elasticity-keys-to-velocity, 10/27/2014