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Unreliable at the Boundary: Analysis of Two Sub-Optimum Crossbow Trigger Designs

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Abstract

It is a fundamental principle that any weapon activated by a trigger — whether a crossbow, pistol, rifle, or shotgun — should only fire when the safety is set to the FIRE position, and the trigger is pulled. This study examines two distinct crossbow trigger designs associated with injuries. In the first crossbow, the trigger safety can be unintentionally or intentionally moved to an "intermediate" position (a point on the edge between SAFE and FIRE). This setting creates uncertainty, leading to instances where the crossbow discharges unexpectedly, either during arrow handling or even after sitting idle with no user action. In the second crossbow design, if the bowstring is not drawn with enough force, the safety fails to fully lock in place, resulting in the sear providing inadequate support to the corresponding release component. This creates a hazardous situation, observed to cause unintended discharge and injury to the user without any trigger activation. In both cases, the injuries did not stem from deliberate misuse; instead, the archer was operating the crossbow in a reasonable way that slightly deviated from the manufacturer's intent.

Keywords

Anti-dry fire, crossbow, failure analysis, false safety, inadvertent discharge, trigger, forensic engineering

Introduction and Historical Background

The crossbow, an ancient weapon, continues to hold significant value in contemporary applications for hunting and recreational shooting. Unlike vertically oriented compound bows, crossbows are typically fired from the shoulder in a manner akin to rifles, offering superior accuracy at extended ranges. The predominant design of modern commercially successful crossbows features a traditional layout, comprising an axial stock (or barrel) with limbs positioned laterally, constructed from advanced metal alloys and synthetic composites. Most modern crossbows incorporate eccentric cams, utilizing a bowstring and multiple power cables to enhance performance. Domestic manufacturers have largely adopted the term "arrows" for crossbow projectiles, phasing out the historical terms "bolts" and "quarrels." While contemporary crossbow designs remain unmistakably recognizable, they differ markedly from their traditional counterparts, as illustrated in **Figure 1**, which depicts a modern narrow, high-velocity crossbow.

With the relaxation of crossbow hunting prohibitions in multiple states, there has been a market-driven increase in crossbow performance. There appears to be a goal of allowing crossbows to compete with rifles for mid-sized game such as white-tailed deer, and at least one manufacturer has rather optimistically advertised its latest model with the tagline "Meet your next rifle[2]." However, compared to even muzzle-loading rifles, crossbows are short-range weapons.

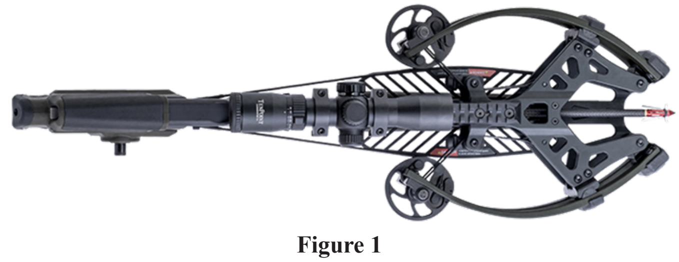

Figure 1
Modern narrow compound crossbow as of 2025, which is capable of 410 fps arrow speed[1].

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The newest crossbows, which launch 400-grain arrows at 500 feet per second, develop approximately 220 ft-lbs of kinetic energy. This is approximately 10% of the kinetic energy at the muzzle of a 30-30 Winchester cartridge, which discharges a 150-grain bullet at 2,390 feet per second, producing ~1,900 ft-lbs of kinetic energy with a much flatter trajectory. In addition to new patents, innovations by crossbow designers have produced dedicated tooling and machines for parts production and assembly, telescopic sights, composite stocks, sophisticated fiberglass construction for the limbs, increased-strength synthetic filament flexible cables and bowstrings, and carbon-fiber shafted arrows. Important patented innovations include the reverse limb layout[3], complex trigger systems including mechanical arrow presence sensors[4], discharge noise attenuation accessories[5], flight rail finger guards[6], reverse draw cam bowstring layout[7], helical power cables[8], narrower limbs[9], and innovative power cable anchoring[10].

It has been the goal of designers to increase arrow velocity and kinetic energy, improve accuracy, reduce vibration, suppress cocking and discharge sounds, and diminish weight and size, all while maintaining durability and affordability. As an example of how advanced the trigger mechanism is in at least one modern crossbow design, see the X-ray in **Figure 2**, which details the significant number of interconnecting components. At the lower right of the image is the polymer pistol grip with the trigger shoe just visible. This trigger interface pivots about an axle, moving an actuating bar backward to trip the clasp through intervening linkages.

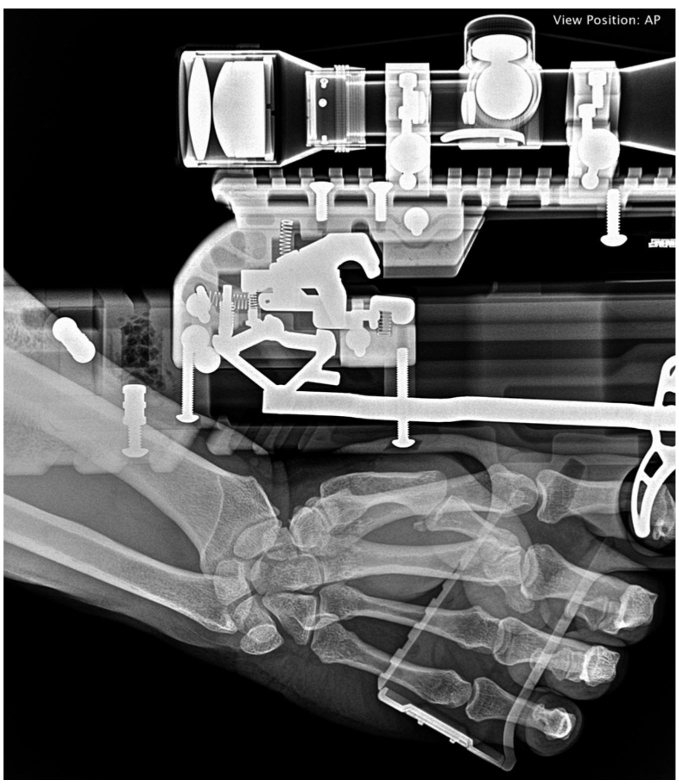

Figure 2
Modern crossbow trigger mechanism, safety off, trigger drawn, and bowstring clasp up.

The design, manufacture, and sale of crossbows in the United States remain largely unregulated at the federal level. Notably, crossbows are exempt from the provisions of the National Firearms Act of 1968[11] and are not subject to federal age restrictions for purchase or possession. The Archery Trade Association (ATA) [https://archery-trade.org/] provides a limited set of voluntary guidelines[12], which outline standardized measurements for archery equipment specifications, such as force-draw and let-down curves for recurve and compound bows. However, these guidelines, first issued in 2009 and most recently revised in 2021, were not developed in accordance with American National Standards Institute (ANSI) protocols. They are adopted solely voluntarily by ATA member companies and do not address safety standards, even indirectly.

At the state level, regulations primarily focus on the use of archery equipment, including crossbows, in hunting and public activities. No federal or state regulations specifically govern crossbow safety or design standards, leaving a significant gap in oversight for these devices.

This paper examines two forensic case studies involving crossbows that inadvertently discharged, resulting in injuries to their users. Both incidents were investigated using a standardized protocol to identify or confirm the mechanism of bowstring release without trigger activation. The analysis highlights that an unreliable crossbow may discharge unexpectedly without exhibiting mechanical failure or visible damage.

General Protocol for Studying an Inadvertent Crossbow Discharge

1. Read the owner's manual. Identify any omitted, unclear, or ambiguous instructions. Understand the mechanism as described in the manual.

2. Acquire and read promotional written materials; watch user instructional videos.

3. Inspect the incident crossbow visually. Read the warning stickers, and document the model and the serial number (if present). Look for cracks in the limbs and other structural components, the

condition of the bowstring and cables, evidence of impact damage to the cams, gap size between the limbs and risers (if any), loose fasteners, evidence of contamination, missing parts, and wear. Do not proceed with cocking, loading, and discharging this crossbow if it is unsafe to do so. Look for evidence that the crossbow was dropped. Look for evidence of cam and/or limb impact. Consider using personal protective equipment (PPE), such as latex gloves and impact-resistant eyewear, and look for blood or other potential biohazards.

4. Inspect the arrows, including the nocks, and any associated material included with the incident crossbow.

5. Conduct a preliminary functions test of the crossbow without cocking or shooting it. A shortened arrow stub can be used to actuate the arrow presence sensor, and a lightly stretched elastic band or taut, loose bowstring can substitute for a bowstring drawn tightly by the limbs. Test the safety, trigger, and clasp — and the arrow presence mechanism.

6. Conduct a functions test of the crossbow by shooting it in accordance with the owner's manual instructions. Draw, load, and discharge properly weighted arrows numerous times for function familiarity. Examine the behavior of the safety when it is engaged, ensuring that the trigger does not release the internal sear. Verify the average measured trigger pull weight, compare the average with the published value, and determine any trigger pull-to-pull force variance. Evaluate the grouping of arrow shots as an indicator of a possible mechanical issue.

7. Examine, if available, blueprints and patent documents. Note that a patent typically visually describes the preferred instantiation of the invention at the time of submission, and the commercialized version may have differences — even substantial details — compared to the patented design.

8. Acquire an exemplar crossbow for disassembly. Determine if any design changes have been made. A comparison with earlier and/or later models may be necessary to determine whether any functional parts have been revised by the designer or manufacturer.

9. Use X-ray or CT [computed tomography] scanning to examine the internal trigger parts and/or other visually inaccessible parts. Compare to a scan of an exemplar as necessary.

10. Conduct a rubber mallet test, inputting a reasonable acceleration to the crossbow from a variety of vectors to see if an acceleration impulse will prompt the sear to disengage the bowstring clasp [see, i.a.,[13]]. Do this testing both with the safety engaged and with the safety disengaged. It is essential to keep safety in mind during this testing as the crossbow may unexpectedly release the drawn bowstring.

Thoroughly and formally document all observations and findings to ensure precision and traceability. The inspection checklist provided earlier constitutes a preliminary assessment. Once the incident mechanism is sufficiently understood, it is prudent to pause for reflection prior to further analysis[14]. This strategic pause facilitates careful planning and enhances the rigor of the investigation. Address the following key considerations:

- What potential factors could lead to an unintended outcome?
- Can the conditions causing an inadvertent discharge be intentionally reproduced for controlled analysis?

For a more comprehensive analysis, consult the following sources:

- Online archery forums for accounts of comparable incidents.
- The Consumer Product Safety Commission (CPSC) database for relevant product recalls.
- Manufacturer websites, which typically publish recall notices.
- Customer reviews to identify recurring issues or patterns associated with the incident crossbow model.
- Surveillance footage of the inadvertent discharge, if it exists.

This methodical approach ensures a comprehensive and systematic investigation, which will support reliable forensic engineering conclusions.

A primary cause of inadvertent discharges in crossbows, as with firearms, is deviations by the user from the intended use envisioned by the designers. Such deviations may not constitute abuse, but could be classified as misuse from the designers' perspective. It is a well-established principle that user behavior varies significantly, encapsulated in the adage "results vary." Each operator interacts with the weapon in a manner that is subtly or markedly distinct from others. This variability underscores the importance of analyzing the mechanism and exploring how different inputs can alter its function.

To thoroughly investigate potential misuse, consider how each operator action could be performed differently or incorrectly. For every intended function, evaluate the following:

- How might the action be executed incrementally differently from the prescribed method?
- Could the action be deliberately performed incorrectly, and what would be the outcome?

A non-exhaustive list of user input variables includes:

- The arrow may not be inserted as far axially rearward onto the bowstring as possible.
- The safety switch may not be moved fully from SAFE to FIRE, or vice-versa.
- The trigger may be pulled partially (but not fully), and the crossbow trigger safety is not then returned to the SAFE position.
- The trigger may be pushed forward, rather than pulled backward.
- The arrow's cocking vane may be inverted, making the arrow 180° out of rotational position.
- The bowstring may be worn beyond its need for replacement, diminishing the center diameter.
- The bowstring may not have been pulled fully backward during the cocking cycle.
- The crossbow may have been dropped.
- For a pristine new crossbow, a user may "baby" the mechanism in an unintentional attempt to ensure the crossbow isn't damaged. This is a mistake, but it occurs. For weapons, authoritative positive inputs are best.

Case Study 1

In the initial unintended discharge incident, the owner acquired the crossbow in new but non-standard condition, as depicted in **Figure 3**. The crossbow, which was assembled from factory components, lacked a serial number sticker, indicating that it was neither sold through wholesale nor retail channels. Instead, it was privately sold by an employee of the local crossbow factory to an acquaintance. This modern crossbow, constructed from synthetic materials, belongs to an earlier design generation compared to the model shown in **Figure 1**. It was assembled circa 2017 and features an optical sight, a rudimentary anti-dry fire (ADF) mechanism (components that prevent cocked bowstring discharge in the absence of an arrow), cams (rotating wheels at the outboard position of the limbs), and power cables crossing beneath the barrel (the axial "flight rail" of the crossbow).

According to the user's testimony, he had taken his crossbow hunting for the first time, and he was hunting deer from elevation. The crossbow was cocked but not loaded with an arrow, with the safety at least partially engaged. He rested his right hand on the crossbow flight rail, and no part of his body was touching the trigger. The crossbow discharged, and the bowstring sliced through his hand, severing his middle finger. Subsequent investigation showed that there had been multiple reported OSIs (other similar incidents) of this crossbow inadvertently discharging and causing user injury. These reports were found in warranty claims, internet archery discussion forums, and litigation.

An inspection of the crossbow was performed, including removal of the trigger mechanism, as shown in **Figure 4**. Similar to the crossbow trigger mechanism previously

Figure 3
Case Study 1 incident crossbow assembled circa 2017.

Figure 4
Incident crossbow showing removal of trigger mechanism and scope mount with draw bar leading to trigger shoe.

x-rayed (**Figure 2**), the bowstring center is anchored by the clasp, substantially behind the trigger shoe user interface, to produce a shorter overall length. Note: The "trigger shoe" is the typically curved, vertically disposed lever that the archer pulls with his release trigger finger. Movement of the trigger shoe – typically through intermediary components – causes bowstring release.

The trigger shoe pivots on an axle and pulls an internal trigger draw bar forward, which is mechanistically opposite that of the crossbow previously shown as **Figure 2**, for which the trigger shoe pushes a transfer bar backward.

Figure 5 shows the trigger mechanism removed from the crossbow stock with the trigger draw bar rotated backward. The basically rectangular stamped steel housing is perforated to mount transverse pins that act as axles, torsional spring posts, and component stops. An internal-stamped steel leaf spring near the top of the housing is

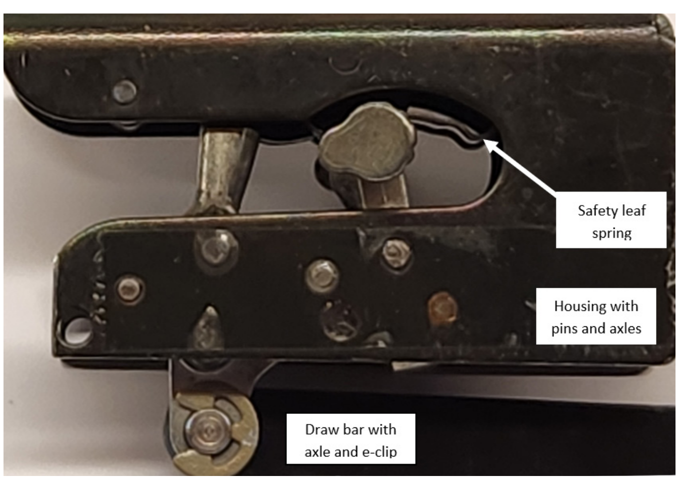

Figure 5
Incident crossbow trigger mechanism, ready, with the safety in the FIRE position with trigger draw bar folded ~180° rearward.

indicated with a white arrow in **Figure 5**. Recesses in the spring act as detents to keep the pivoting safety lever either fully forward or backward.

The trigger mechanism components and their axles were removed from the stamped steel box housing, and longer gage pins were inserted into the component axle holes from the left side to facilitate a positional layout of the major moving components, as shown in **Figure 6**. The multiple torsion springs, which bias individual component motion, are not shown. The biasing springs rotate the anti-dry fire (ADF) lever DOWN, the clasp VERTICAL, the tumbler ENGAGED (as shown, fully counter-clockwise), and the safety fixed either fully forward or backward as a detent. In **Figure 6**, the sear surface of the tumbler is in the engaged position — such that the clasp cannot rotate forward counter-clockwise into its released position.

To cock this model of crossbow, a rope cocking device with two hooks is attached to the bowstring on either side of the barrel. The user places his foot in the stirrup at the discharge end of the crossbow and pulls the two handles of the rope cocking device upward toward his shoulders. See **Figure 7** for an explanatory image of the cocking of the incident crossbow. The two hooks ensure that the center portion of the drawn bowstring is locally flat and perpendicular to the flight rail, and the bowstring itself (blue arrow) glides over the clasp and causes it to rotate out of the way (white arrow). At full draw, the safety rotates clockwise, and its bottom U-shaped cavity engages against the mating surface of the tumbler (yellow arrow), restraining

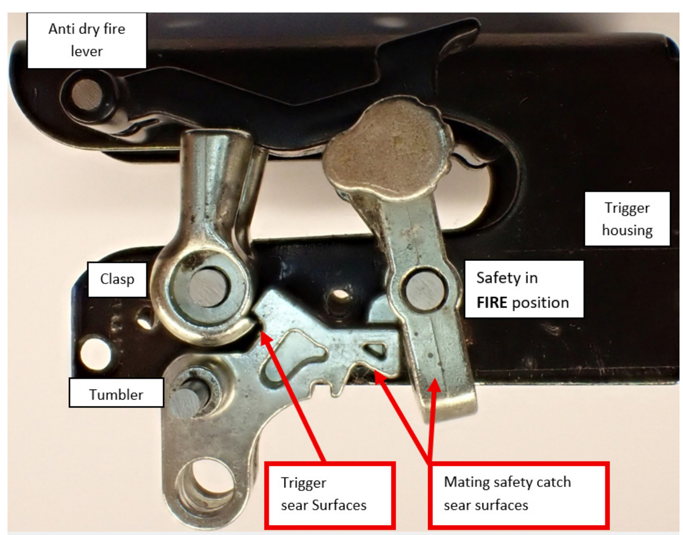

Figure 6
Incident crossbow trigger mechanism with internal components and axles removed with the four major components affixed to the left exterior side of the housing and the trigger bar removed from the sear.

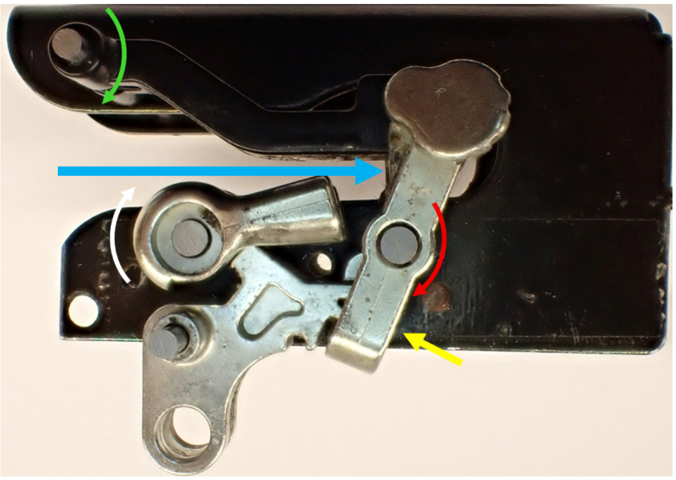

Figure 7
Incident crossbow trigger mechanism showing full draw position of bowstring represented by a blue arrow.

it from rotational motion. Also at full draw, the ADF rotates downward (green arrow). It will prevent the safety from rotating back to the FIRE position until the ADF is rotated back upward by the insertion of an arrow and nock onto the bowstring.

Figure 8 shows the trigger mechanism components as they are positioned at the moment of firing. The ADF lever had been moved up by the presence of the arrow. The safety was then moved forward to the FIRE position. The draw bar pulled the tumbler such that it rotated clockwise, disengaging the tumbler's sear surface from the mating surface of the clasp. The unconstrained clasp rotated ~90° counter-clockwise and released the bowstring and arrow, which rapidly moved forward (left) as represented by the blue arrow.

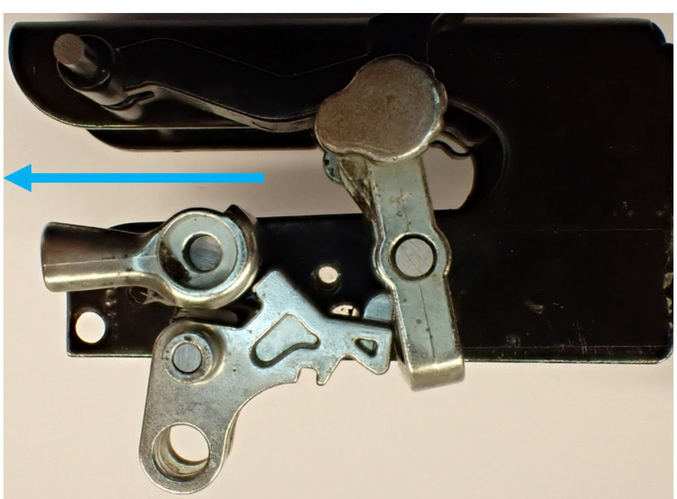

Figure 8
Incident crossbow trigger mechanism showing discharge position.

Analysis and physical testing of the incident mechanism revealed that the most likely situation was consistent with the testimony of the crossbow owner and other users who complained of inadvertent discharge. By pulling the rope cocking mechanism backwards incompletely, the clasp would index and accept the bowstring while not fully pushing the safety to its full SAFE position. This is illustrated in **Figure 9**. As is shown with the dismounted components, the tumbler and safety can each be in the partially engaged position if the crossbow is not vigorously cocked by the rope cocking device.

This is also shown with the components properly assembled in the crossbow. The top image of **Figure 10** shows the safety in the fully SAFE position without the bowstring present. Note that the ADF lever has moved downward, blocking forward motion of the safety if no arrow is loaded. The lower image of **Figure 10** shows the cocked crossbow with the bowstring and clasp in the proper position, but the ADF and the safety are not in the proper position. This miscocked condition was deliberately produced by a minimal rope cocking device pull for which the bowstring would index the clasp but not move the top of the safety lever fully rearward.

Based upon analysis and investigation of the incident crossbow, it was determined that this trigger design was sub-optimal. It was found that the ADF lever, while somewhat valuable, was not "active" in that the safety could be moved to FIRE after an arrow was loaded. Then if the arrow were removed, the safety would not automatically return to SAFE. In addition, the geometry of this mechanism was such that the bowstring could be deliberately or

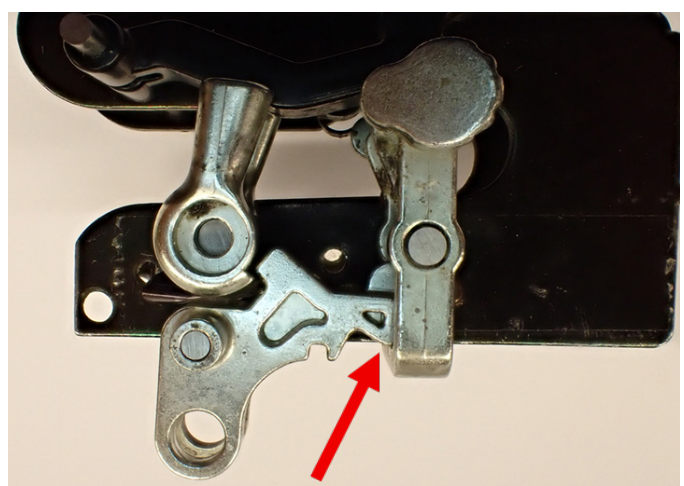

Figure 9
Incident crossbow trigger mechanism showing position in which the tumbler is barely constrained by the mating ledge of the safety (see red arrow).

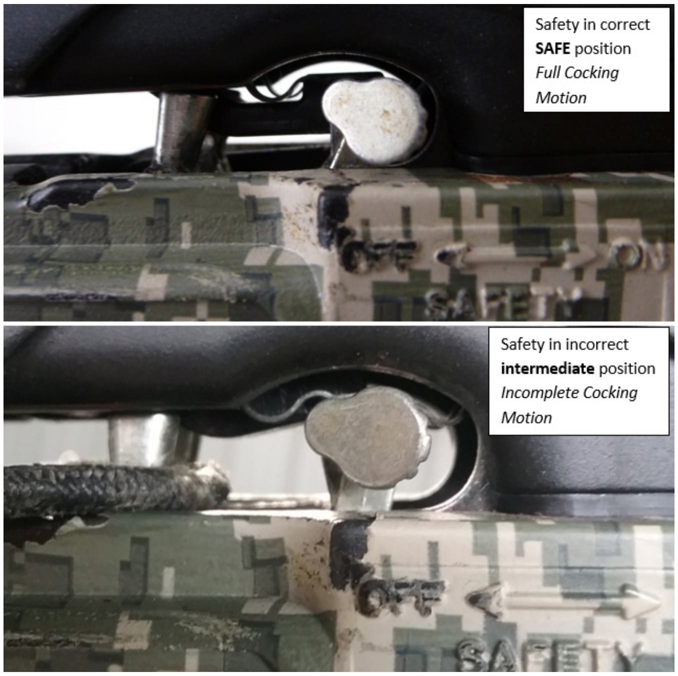

Figure 10
Incident crossbow safety and ADF lever showing the proper position when drawn at top (bowstring not shown), and an incorrect intermediate position at bottom with the ADF not actuated and the tumbler not fully constrained, if at all.

unintentionally cocked with the clasp in the proper position without the safety being moved to the full SAFE position to engage the tumbler completely. This design is no longer in production and has been replaced by more sophisticated and ostensibly more reliable designs.

Case Study 2

The second crossbow design evaluated in this study represents a significant technological advancement over the "value" crossbow model described in Case Study 1, despite their brief concurrent market presence. Introduced in 2016 by Ravin, a startup company founded to develop and market this design, this premium model features composite construction materials, relatively short power cables that do not cross under the barrel, and helical power cable journals facilitating a compact limb arrangement. Unlike many designs (e.g., Case Study 1 crossbow), this crossbow omits a foot stirrup as it incorporates an integrated crank cocking mechanism to draw the bowstring. This design also features an internal ADF trigger mechanism intended to allow the crossbow to only fire when an arrow nock is fully engaged to the center of the bowstring (**Figure 11**).

Despite its commercial success, the model faced significant safety challenges. Reports of unintended discharges led to a prompt recall in collaboration with the Consumer Product Safety Commission[15]. While the recall officially targeted the proprietary clip-on arrow nocks, the primary defect lay in the internal trigger components, which permitted hang fire (a hazardous unpredictable delayed discharge after trigger pull) and subsequent accidental discharge, even with replacement nocks. To address this, Ravin redesigned several trigger components, integrating them into later production runs and offering one-to-one parts replacement as a silent recall measure for customers returning early R9 and R15 models for repair. The R15, an enhanced version of the R9, features stronger limbs and increased arrow velocity but shares the same foundational design.

Figure 11
Photograph of the crossbow design of Case Study 2, Ravin R9 / R15 at top, along with a close-up of the trigger shoe and trigger pack at bottom.

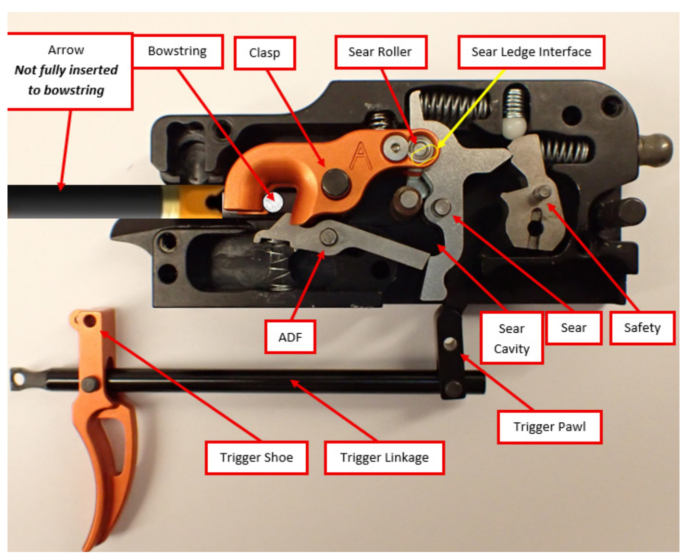

Figure 12
Photograph of the generation 1 trigger mechanism in the cocked but unloaded position.

Figure 12 illustrates the dismounted and partially disassembled "generation 1" (that is, originally marketed) trigger mechanism of the Ravin R9 and R15 crossbows, which are detailed in the associated patent[16]. To enhance visibility of key components, the left cover of the trigger housing has been removed. For clarity, a digital representation of an arrow stub equipped with an orange post-recall nock and a circular depiction of the bowstring cross-section, held by the clasp, have been superimposed. Red arrows, used to label component nomenclature, indicate the rotational axes of the respective parts where applicable. A yellow rectangle highlights the concealed sear ledge interface, which must disengage to enable crossbow discharge. The arrow retention actuator and its forward coil spring (located ahead of the clasp) have been omitted, as has the trigger shoe return spring, typically anchored at the forward holes of the trigger shoe and trigger linkage.

When the crossbow is cocked, the clasp is in the down position, and it retains the tensioned bowstring until the sear disengages, releasing the clasp, bowstring, and arrow. As depicted in **Figure 12**, the clasp is prevented from rotating to the open position by the sear's interfacing sear ledge surface. The clasp's sear roller, a cylindrical hardened steel pin, is transversely mounted within the clasp and supported by sealed ball bearings on both sides. The trigger mechanism of **Figure 12** is shown with the safety in the SAFE position, locking the sear against clockwise rotation. Additionally, the ADF lever blocks sear rotation in this illustration, as the digitally inserted arrow has not been fully inserted rearward to push down the ADF lever's leading nose (see green arrow in **Figure 13**, which shows the trigger mechanism in the discharged configuration). For the sear to release the clasp, two conditions must be met: the user must rotate the safety to the FIRE position, and the ADF lever must be rotated counterclockwise by the full insertion of an arrow. After firing, the clasp moves to the upward position, the ADF endform rests within the sear cavity, and the safety automatically returns to the SAFE position.

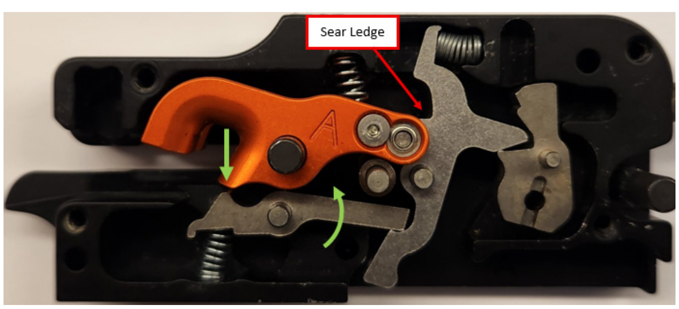

Figure 13
Photograph of the generation 1 trigger mechanism in the discharged position with the ADF lever inside of the sear cavity and the green arrows indicating the direction of ADF travel to disengage the ADF and allow sear rotation.

The typical loading and discharge cycle of the Ravin R9 and R15 crossbows operate as follows. The trigger pack is released from its rearward-firing position and advanced to engage the bowstring. The clasp descends to capture the bowstring, and the safety remains in the SAFE position. Using the integrated ratcheted cranking mechanism, a fabric belt pulls the trigger pack and bowstring rearward, cocking the bowstring. Once fully retracted, an arrow is inserted into the front of the trigger pack, and the polymer arrow nock securely clips onto the bowstring serving (transverse filament windings) at the bowstring's midpoint. This action depresses the ADF lever nose, pushing the rear endform upward to align it with the sear cavity to enable discharge. The user then pushes the safety tactile (button) forward to disengage the safety's internal blocking surface away from the sear, switching to the FIRE position. To discharge, the trigger shoe is pulled rearward, driving the trigger linkage backward. This linkage motion causes the top of the trigger pawl to move forward, contacting the bottom rear face of the sear. The sear rotates clockwise, disengaging the sear ledge from the sear roller, allowing the clasp to release the bowstring and propel the arrow.

The sequence of user crossbow actions that produced inadvertent crossbow discharge multiple finger injuries followed a regularly described pattern:

1. The archer cocks the crossbow using the integral crank mechanism, which automatically engages the physical blocking safety against the sear. The user interface button is below the safety rotation axle, so that the button moves backward to the SAFE position and displays a white dot, while the internal ledge, which is above the axis of rotation, moves forward and supports the sear.

2. The archer loads a factory arrow with its clip-on nock. The nock clicks and vibrates upon interaction with the bowstring, giving the user both tactile and audible feedback of success. The bottom surface of the arrow nock rotates the ADF lever from its fully engaged at-rest position, but not completely, putting it in a position that will prevent it from entering the sear cavity upon trigger pull. That is, the ADF is rotated into an intermediate position (**Figure 14**), with a prominent

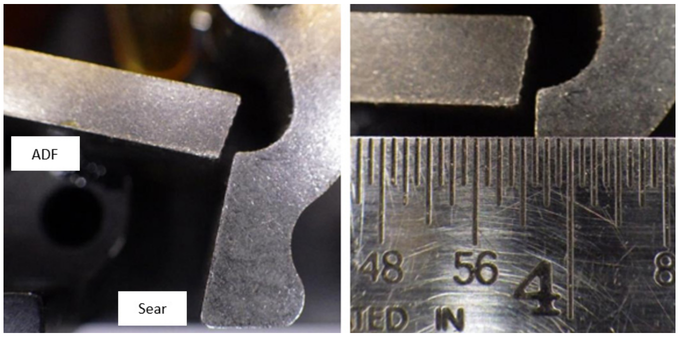

Figure 14
Photographs of the generation 1 ADF and sear in the intermediate position with the ADF trailing edge not completely clearing the entrance to the sear cavity.

gap between the ADF endform and the sear. This gap is objectionable; it allows the sear to rotate enough to assume an unsafe and unstable position.

3. The crossbow's safety button is pushed forward, concealing the white SAFE dot and revealing the red FIRE dot. This motion rotates the internal safety ledge rearward to the FIRE position, disengaging it from the mating surface of the sear.

4. The archer's trigger finger pulls the trigger shoe, causing the front surface of the trigger pawl to press against the back surface of the sear and rotate it slightly, taking up the gap between the sear and the ADF lever. As the ADF lever is only partially aligned with the sear cavity's entrance, it prevents the sear from fully rotating. As a result, the sear roller shifts beyond the supporting point on the sear ledge (**Figure 15**), exerting considerable force and prying the sear toward the discharged position. The red arrows in **Figure 15** highlight the insufficient support of the clasp's sear roller by the sear ledge, indicating a design error.

5. The actions of the sear, ADF, and clasp have placed the crossbow's trigger into a semi-stable, dangerous configuration. The sear roller teeters on the radiused end of the sear ledge, while the sear is prevented from fully disengaging due to the blocking ADF.

6. The user, informed by the Ravin R9 / R15 crossbow manual and instructional videos that the crossbow cannot fire with a partially engaged arrow, attempts to re-engage the safety by pushing the safety button rearward (away from the discharge end). However, the internal safety mechanism only partially moves and becomes fixed in an unstable intermediate position — unable to fully engage beneath the sear's horn (**Figure 16**). The sear obstructs the safety's path, preventing proper engagement.

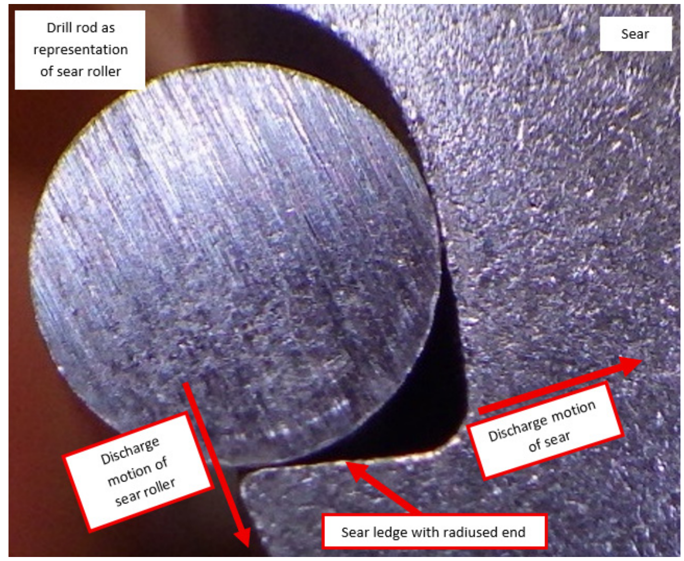

Figure 15
Drill rod in the same diameter as the sear roller resting on the sear ledge, showing that the contacting point of the cylinder is incrementally past the point of edge radius initiation with red arrows representing discharge motion direction.

7. The archer, confident that the manual safety has fully engaged due to the familiar actuation resistance and audible click, observes the external safety button's window indicator displaying half of the white SAFE dot and half of the red FIRE dot. Unaware of the crossbow's internal mechanics, the novice user does not realize that the Anti-Dry Fire (ADF) mechanism, sear, clasp, and safety are all in unstable intermediate positions,

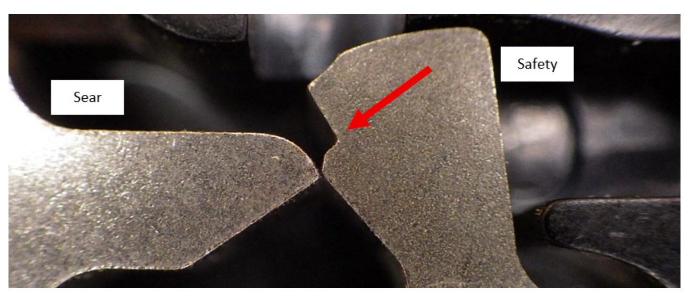

Figure 16
Generation 1 sear in the intermediate position at left and the safety at right in the FALSE SAFE position, with the red arrow showing both the direction of motion of the safety against the sear and the unengaged safety ledge.

precariously holding the immense tension of the drawn crossbow limbs.

8. The archer, having unsuccessfully attempted to engage the safety and with no finger on the trigger, firmly grasps the arrow shaft and forcefully inserts it into the trigger pack to re-seat the nock. This backward force on the arrow causes the ADF lever to rotate, disengaging from contact with the sear and entering the sear cavity. Although the safety was moved toward the SAFE position, it failed to engage properly; the sear roller pushed past the sear ledge, causing the clasp to release and the arrow to discharge. This sudden release invariably resulted in injury to the archer from the arrow's vanes or the bowstring. Some archers, trusting the crossbow's reliability, attempt to re-seat the arrow with their fingers in the bowstring's path, mistakenly believing that the crossbow could not fire since no finger was actuating the trigger, and the safety appeared to be engaged.

To validate the mechanistic feasibility of the incident sequence, crossbows involved in user injuries were individually tested using modified arrow nocks. These modifications enabled a cock/load/trigger pull sequence with the ADF lever positioned at various angles. Specifically, the bottom surfaces of polymer nocks were incrementally filed to reduce the ADF lever's rotation when an arrow was fully inserted. Minimal filing had a negligible impact on the ADF lever's rotation, whereas extensive filing prevented arrow discharge by entirely restricting the sear's rotation. The objective was to identify an "intermediate" degree of filing that replicated the conditions leading to user injuries and to document the crossbow's characteristics when this intermediate condition manifested, as shown in **Figure 17**.

As anticipated, the intermediate position was reliably replicated by iterative nock filing. When the ADF lever was rotated incompletely and into the intermediate position, the cocked and loaded crossbow would make a subtle clicking sound when the trigger shoe was pulled, signifying the internal unstable re-arrangement of components, but no arrow discharge. This indicating sound was not recognized by unsophisticated archers who had no knowledge of trigger mechanism defect. When the safety button was pushed forward during filed nock testing, the safety position indicator window reliably indicated that the crossbow was neither set to SAFE nor to FIRE (**Figure 18**). This subtle indicator of the crossbow's intermediate position was also not recognized by the users.

All crossbows tested in the intermediate position, with the safety mechanism set to the FALSE SAFE state, underwent further evaluation by re-seating the arrow shaft and nock into the trigger pack using a shaft-gripping implement. In every instance, this action resulted in immediate crossbow discharge (**Figure 19**).

To document the extent of the issue, photographs were taken of multiple Ravin R9 and R15 Generation 1 trigger design crossbows with their safety mechanisms in the FALSE SAFE position, confirming a systemic design flaw rather than isolated incidents. Additional tests were conducted to evaluate crossbow performance, including:

Figure 17
Jeweler's file and Ravin crossbow filed nock on the side with the index vane — the bottom surface of the arrow when inserted into the trigger pack.

Figure 18
Ravin R9 crossbow safety showing the intermediate FALSE SAFE position with half of the SAFE white dot showing and half of the red FIRE dot showing.

Figure 19
Author deliberate re-seating of an arrow in an incident crossbow using an implement causing discharge without a finger on the trigger — notice the arrow vane which has dislodged as a result of the discharge.

- Force testing of the safety button motion when engaged into the normal SAFE position and into the FALSE SAFE position when the internal components were in the intermediate misfire position.

- Sound testing of safety button when engaged in the normal SAFE position and into the FALSE SAFE position.

- Analysis and testing of the redesigned trigger mechanism, as shown in **Figure 20**. The same filed nock testing was performed on this trigger, and this mechanism demonstrated superior performance when compared to the generation 1 trigger. Pull testing of both the generation 1 and generation 2 triggers was performed. Based upon the testing, it required more force to discharge the generation 2 trigger-equipped crossbows, as expected, due at least in part to an increased engagement of the sear roller to the sear ledge surface of the sear.

Figure 20
Photograph of the generation 2 trigger mechanism documenting geometric changes at ADF / sear interface amongst other improvements.

Laboratory testing of the incident crossbow trigger design substantiated the eyewitness accounts of the multiple injured users, confirming that their crossbows discharged unexpectedly during arrow reseating. These incidents occurred under the following conditions: (A) after a misfire; (B) following re-engagement of the safety mechanism as outlined in the user manual; (C) without subsequent trigger activation; and (D) during the manual reseating of the factory-supplied arrow. Changes were made to the ADF lever, sear, sear roller, and other components of the generation 1 trigger mechanism as a comprehensive upgrade, making the generation 2 trigger that has shown to be substantially more reliable.

Summary and Conclusions

In forensic investigations of manufactured products, the terms "abuse" (typically meaning intentional wrongdoing) and "misuse" (typically meaning error in use) are often conflated. However, using a consumer product in a manner slightly deviating from the owner's manual does not necessarily constitute an "abuse." This analysis examined two case studies involving distinct crossbow designs, highlighting failures at critical operational boundaries.

In the first case study, the bowstring was drawn with less force than anticipated by the designers, resulting in a failure to fully cock the crossbow leaving the automatic safety disengaged. This issue delineates the boundary between the completely cocked and uncocked states. In the second case study, a boundary was identified between a fully inserted arrow, which enabled expected performance and an incompletely inserted arrow that prevented the sear from releasing the clasp, revealing a latent defective intermediate position. Variations in the anti-dry fire (ADF) lever rotation were attributed to differences in bowstring serving diameter, the force applied by users during arrow insertion, and standard manufacturing tolerances.

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