

Reaching Hearts

A 6×6 Romeo & Juliet line slot — a calm moonlit base game carried by sticky vertical wilds whose multipliers *add*, split across two bonuses: one you can fall into, one you can only buy.



GAME RTP

~96.2%

VOLATILITY

Med / V.High

MAX WIN

15,000×

GRID

6×6 · 6 Lines

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Original concept, math design, Monte-Carlo validation, art direction & engineering. All figures sourced from the game's real configuration and simulation harness — 2,000,000-spin base runs, 1,000,000-round bonus runs, an independent closed-form cross-check, and bit-for-bit game ↔ sim parity. Confidential design document.

1 Overview

Reaching Hearts is an original 6×6, 6-payline slot set in a moonlit Renaissance Verona. Lines pay left-to-right from the leftmost column, 3 or more matching. The base game is deliberately quiet and inexpensive — it returns 40.26% on its own — because the game is **feature-forward**: the majority of the return is carried by the bonus, where **Romeo and Juliet are not reel symbols at all**. They exist only as the vertical wild the feature creates.

In the bonus, a rose drops into a column, the board freezes, and the column re-spins behind a wall of fire. If the opposite-coloured rose lands, the entire column becomes wild — Juliet on the balcony above, Romeo reaching up from below — and it carries a multiplier. Wilds are **sticky** for the rest of the round, so coverage only ever grows.

THE HOOK — MULTIPLIERS THAT ADD, NOT MULTIPLY

Every wild fills a *whole column*, so every payline crosses every wild. A row's multiplier is the **SUM** of the multipliers of the wild columns it crosses — three wilds at 50×, 100× and 25× give **+175×**, not 125,000×. That single decision is why the max win is a controlled 15,000× instead of an unbounded number, and it is what makes coverage — not luck on one cell — the thing the player is chasing.

ATTRIBUTE	VALUE
Title	Reaching Hearts
Grid / mechanic	6×6, 6 fixed paylines (the 6 rows), left-to-right from column 0, 3+ matching, wilds substitute
Paying symbols	10 paying (5 royals + 5 high) + WEDDING RING scatter + in-bonus rose triggers
Theme / style	Renaissance Verona · Romeo & Juliet · baroque gold & velvet
Base game RTP (base only)	40.26% (38.83% line + 1.43% scatter)
Total game RTP (with natural trigger)	~96.2%
Bonus modes	THE SONNET (natural + buy) · THE TRAGEDY OF VERONA (buy-only)
Volatility class	Medium (Sonnet) · Very High (Tragedy)
Max win	15,000× bet (per-bonus cap)
Engine / stack	TypeScript (strict) · PixiJS v8 · Vite

2 Key Stats

TOTAL GAME RTP

96.2%

Base total + natural Sonnet trigger · 2M
base + 1M bonus sim

SONNET AVERAGE

71.12×

Medium volatility · 1M-round sim

TRAGEDY AVERAGE

141.79×

Very high volatility · 1M-round sim

MAX WIN

15,000×

Validated per-bonus cap

METRIC	VALUE	VALIDATION
Total game RTP	~96.2%	2M base + 1M Sonnet MC; closed-form cross-checked
Base LINE RTP	38.83%	2M-spin sim · analytic 38.79% (z = +0.59)
Base SCATTER RTP	1.43%	2M-spin sim · analytic 1.43% (z = +0.06)
Base TOTAL RTP	40.26%	2M-spin sim · analytic 40.22% (z = +0.58)
Base hit frequency	26.54%	2M-spin sim (530,787 winning spins)
Sonnet natural trigger	1 in 127.2	exact Binomial · measured 1 in 126.6 at 2M
Sonnet average payout	71.12×	1M-round sim (SE ±0.41×)
Tragedy average payout	141.79×	1M-round sim (SE ±0.76×)
Sonnet buy RTP @ 75×	94.82%	E ÷ buy price · see \$5
Tragedy buy RTP @ 150×	94.53%	E ÷ buy price · see \$5
Sonnet cap-hit rate	0.0040%	1M-round sim (40 caps) ≈ 1 in 25,000
Tragedy cap-hit rate	0.1024%	1M-round sim (1,024 caps) ≈ 1 in 977
Game ↔ sim parity	bit-for-bit	100k seed 1 through the real game modules
Line-evaluator selftest	0 / 300,000	zero mismatches vs brute-force reference

PARITY IS THE HEADLINE

The RTP above is not "what the simulator says." A headless harness that imports and runs the *real shipped game modules* reproduces the simulator's numbers to the last printed digit at the same seed — base line, scatter, hit frequency, trigger rate and both bonus averages. The game a player actually spins is provably the game the math describes.

3 Core Mechanics

Base Spin & Lines

Each spin fills the 6×6 grid from a single weighted pool, drawn independently per cell — 36 independent draws with replacement, one RNG step each. The 6 paylines are the 6 rows, each read left-to-right **starting at column 0**; 3 or more matching connected symbols pay. A run that begins in column 1 or later never pays, which is what makes the base game's near-misses frequent and its hit rate a deliberate 26.54%.

Symbol Ranking & Where the Base Return Lives

Ten paying symbols in two tiers. The base reels are intentionally **royal-concentrated**: ten, J and K share the top weight of 238 (25.3% per cell each), which is what buys the hit frequency on a leftmost-anchored line rule. The high symbols are ceiling decoration — they exist to be spectacular inside the bonus under a large additive multiplier, not to carry the base.

SYMBOL	TIER	REEL WEIGHT	LINE RTP	SHARE OF LINE RTP
Friar	1 (top)	3	0.0000%	0.00%
Tybalt	2	5	0.0001%	0.00%
Nurse	3	8	0.0007%	0.00%
Dagger	4	12	0.0014%	0.00%
Love Letter	5 (high entry)	18	0.0062%	0.02%
K	6 (royal)	238	14.3213%	36.88%
Q	7 (royal)	85	0.3965%	1.02%
J	8 (royal)	238	12.0175%	30.95%
10	9 (royal)	238	11.7396%	30.23%
A	10 (royal)	85	0.3472%	0.89%
Wedding Ring (scatter)	Trigger	10.66	1.4339%	— (scatter pay)

Total reel weight 940.66. K / J / 10 carry 98.06% of all line RTP between them. Per-symbol figures from the 2M-spin run.

Scatter & Trigger

The **Wedding Ring** is a non-paying-on-lines scatter that both pays and triggers. Landing 3 or more anywhere on a base spin pays a scatter award *and* triggers **The Sonnet** — at an exact-Binomial rate of 1 in 127.2 spins. Scatter pays are deliberately modest and flat-topped so nothing on the base reels competes with the bonus for the biggest moment.

WEDDING RINGS	PAY (× TOTAL BET)	EFFECT
3	1×	Pays · triggers THE SONNET
4	8×	Pays · triggers THE SONNET
5	30×	Pays · triggers THE SONNET
6+	100×	Pays · triggers THE SONNET

DESIGN NOTE — THE SCATTER CAN ONLY EVER OPEN THE SONNET

The Tragedy of Verona is buy-only. No scatter combination, on any spin, can trigger it — that constraint is enforced structurally: each mode carries a `hasNaturalTrigger` flag and the base loop routes through it, so there is no code path from a base-game scatter to The Tragedy. This is what keeps one honest overall RTP: the base game's return is composed of its lines, its scatters, and *one* natural bonus. The Tragedy is validated independently against its buy price and contributes exactly 0% to the natural game RTP.

4 Bonus Features — The Rose, The Wild, The Sum

Both bonuses are the same engine with two personalities: **10 free spins** on a board where columns convert to sticky, full-height vertical wilds, and every row's multiplier is the additive sum of the wilds it crosses. What separates them is how often roses land and how hot the ladder runs.

The Rose Mechanic — a two-stage trigger

A column converts only if **both** events happen, and the two are kept as separate tunable values even though only their product drives RTP:

STAGE	MEANING	SONNET	TRAGEDY
P ₁	A rose drops into a non-wild column that spin	0.10818	0.15985

STAGE	MEANING	SONNET	TRAGEDY
P_2	The opposite colour lands on the suspense re-spin	0.48	0.275
$P_1 \times P_2$	Conversion per column, per spin	0.05193	0.04396

WHY P_2 IS A FEEL DIAL, NOT JUST A NUMBER

Only the *product* $P_1 \times P_2$ affects RTP — the split between them is free. It is spent on emotion. In The Sonnet a rose that drops lands roughly half the time: hopeful, winnable suspense. In The Tragedy it lands barely a quarter of the time — roses drop *more* often and miss *far* more often. Same maths, opposite feeling: the courtship coaxes, the tragedy denies. RTP tuning moves P_1 ; P_2 is held at its authored value.

The Wild & The Additive Rule

On conversion the whole column becomes wild and draws one multiplier, once, from a fixed ladder — [2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 25, 50, 100] — weighted **cool** in The Sonnet (toward 2–10) and **hot** in The Tragedy (weighted onto 20 / 25 / 50 / 100). The multiplier is frozen for the round. Wilds are sticky, so an early wild multiplies nine more scoring spins.

```
// per spin, for each of the 6 rows
M      = SUM of the multipliers of every active wild column  // additive
row_win = base_row_pay × M                                // wilds substitute
spin_win = row_win × 6 rows
// a full row of 6 wilds pays a flat 20× total bet as its base
// every payline crosses every wild column, so all 6 rows share one M
```

PARAMETER	VALUE	NOTE
Free spins	10	no retrigger
Wild shape	Full column	all 6 rows, sticky for the round
Multiplier ladder	2 → 100	13 rungs, drawn once on formation, frozen
Ladder weighting	Cool / Hot	Sonnet toward 2–10 · Tragedy onto 20/25/50/100
Row multiplier	Additive	sum of crossed wild columns — never multiplicative
Full-wild row pay	20×	flat base for 6 wilds on a row, before M
Cap	15,000×	per bonus, total bet

The Two Modes

	THE SONNET	THE TRAGEDY OF VERONA
Character	The courtship — steady hearts, wins that build	The doom — rare, devastating swings
Volatility class	Medium	Very high
How you get in	3+ scatters (1 in 127.2) or buy	Buy only
Buy price	75× total bet	150× total bet
Average payout (E)	71.12×	141.79×
Median payout	3.30×	4.95×
Std deviation	405.25×	762.32×

	THE SONNET	THE TRAGEDY OF VERONA
Volatility index (uncapped σ/μ)	5.886	7.499
Cap-hit rate	0.0040%	0.1024%
Avg wilds at round end	2.48 / 6	2.18 / 6
Buy RTP	94.82%	94.53%

Both modes at 1,000,000 rounds, seed 1. **Read the uncapped σ/μ , not the capped one:** the 15,000× cap chops The Tragedy's tail so hard that the *capped* figures invert the ordering (5.376 vs Sonnet's 5.698) — an artefact of clipping, not a statement about the modes. Uncapped, the true ordering holds: 7.499 vs 5.886.

Payout Distribution

BUCKET (× TOTAL BET)	THE SONNET	THE TRAGEDY	READ
0 – 1×	35.075%	32.050%	a third of rounds are near-duds in both
1 – 10×	27.759%	25.989%	
10 – 50×	20.587%	18.449%	the Sonnet's bread and butter
50 – 100×	6.636%	7.245%	
100 – 500×	7.150%	11.135%	Tragedy ~1.6× more likely
500 – 5,000×	2.619%	4.704%	Tragedy ~1.8× more likely
5,000 – 15,000×	0.170%	0.326%	Tragedy ~1.9× more likely
15,000× CAP	0.0040%	0.1024%	Tragedy ~26× more likely

Both modes share one ceiling: The Tragedy simply visits the top of the range far more often, and pays for it with a flatter middle. The cap is the mode's signature: roughly 1 bonus in 977 versus 1 in 25,000.

Coverage — what the round is actually about

WILD COLUMNS AT ROUND END	0	1	2	3	4	5	6
The Sonnet (avg 2.48)	4.05%	17.24%	30.33%	28.58%	15.05%	4.25%	0.50%
The Tragedy (avg 2.18)	6.70%	22.88%	32.53%	24.74%	10.54%	2.39%	0.22%

The Tragedy reaches *less* coverage and still pays twice as much — because its ladder is hot. That inversion is the mode in one line: fewer wilds, bigger numbers, and a 6-wild board (0.22% of rounds) that detonates against the cap.

5

Math & RTP Design

The game was tuned sim-first against a Python Monte-Carlo harness that runs the real game logic, then ported to the engine and verified bit-for-bit. Every headline figure below is either measured over millions of rounds, computed in closed form, or both.

RTP Composition

```
// total game RTP — how the ~96.2% is composed
TOTAL = base_total(40.26%)           // 38.83% line + 1.43% scatter
      + natural_trigger(1/127.2) × sonnet_avg(71.12×)  // ≈ 55.9%
      ≈ 96.2%

// The Tragedy of Verona is BUY-ONLY.
// It contributes 0% here and is validated separately against its 150× price.
```

Stated with the measured 1M Sonnet average (71.12x) the total is 96.17%; with the locked reference average (71.4x) it is 96.39%. The ±0.32 pp spread is the standard error of a fat-tailed mean at 1M rounds, not a disagreement — the true figure sits at **96.2 – 96.4%**.

Independent Closed-Form Cross-Check

The base RTP is not only simulated. It is computed analytically from the reel weights and payable — for a symbol with per-cell probability p , a leftmost-anchored run of length r occurs with probability $pr(1-p)$ for $r = 3,4,5$ and $p6$ for a full row; the scatter is an exact Binomial(36, q). Two independent methods, one answer:

QUANTITY	CLOSED FORM	MEASURED (2M)	Δ (PP)	Z
Base LINE RTP	38.7853%	38.8304%	+0.0451	+0.59
Base SCATTER RTP	1.4324%	1.4339%	+0.0015	+0.06
Base TOTAL RTP	40.2177%	40.2643%	+0.0466	+0.58
Sonnet trigger rate	1 / 127.21	1 / 126.6	—	+0.56

Every z-score under 0.6 — agreement to three significant figures on every quantity. A Monte-Carlo run can hide a bug; a closed form that independently lands on the same number cannot.

Buy Pricing — and an honest gap

Both buys are priced on round numbers: **75x** for The Sonnet, **150x** for The Tragedy — a clean 2.0x across price, and close to 2.0x across payout (141.79 / 71.12 = 1.99x). Measured against those prices, the buys return **94.82%** and **94.53%**.

DECLARED: THE BUYS RETURN ~94.5-94.8%, NOT 96%

Both bonus averages land slightly under the round-number targets they were tuned toward (71.12 vs 72, 141.79 vs 144), and at 1M rounds both sit low by roughly 2-3 standard errors *in the same direction* — a systematic undershoot, not noise. The cause is diagnosed: the conversion-rate law was calibrated on a flat all-2s ladder to escape the fat tail, but the all-2s ladder never reaches the 15,000x cap, so the extrapolation to the live ladders slightly over-predicted E and P_1 was set a hair low. It shows up harder in The Tragedy, which caps ~26x more often — exactly as that explanation predicts.

Two honest options existed: reprice the buys to 74x / 148x and return a true 96%, or hold the round prices and declare the real number. **This build holds 75 / 150 and declares 94.82% / 94.53%**. The buys are a slightly worse deal than natural play (96.2%) — that is a stated design position, not a rounding claim, and the rules screen in-game reads the same figures from the same constants.

Key Tuning Levers (in order of leverage)

LEVER	EFFECT
P_1 (rose drop rate)	The primary dial on bonus E. P_2 is held at its authored feel value, so all RTP movement in the bonus goes through P_1 . Sonnet 0.10818 · Tragedy 0.15985.
Ladder weighting (cool / hot)	Drives the <i>shape</i> — buckets, cap-hit rate, the volatility gap between modes. Held frozen during RTP tuning precisely so tuning the mean could not distort the mode's character.
Wedding ring weight	Sets the natural trigger rate (10.66 / 940.66 → 1 in 127.2). Each trigger is worth ~71x, so this moves total RTP fast — it is the slack variable that closes base + trigger×E onto target.
Base reel weights	Royal concentration (ten/J/K at 238) buys hit frequency on a leftmost-anchored rule; A/Q at 85 and the high tier in single digits keep the base lean and feature-forward.
Wild row pay & cap	20x flat for a full wild row, clipped at 15,000x. The cap binds almost exclusively in The Tragedy's tail and is what makes the additive model shippable.

Problems Solved During Tuning

THE PHANTOM BASE RTP. The design carried a base-line RTP of 60.6% and a trigger of 1 in 203 from day one. Neither had ever been measured. The base sim reported **0.49%** — and a closed-form calculation independently returned 0.4886%, proving the number was real and not a sim bug:

the base game genuinely almost never paid. The reels, meanwhile, triggered the bonus roughly **1 in 13** spins, not 1 in 203. Both figures were assumptions that the built game had never matched. Everything downstream was rebuilt from measurements.

THE DOUBLE-COUNTED BONUS. With both bonuses contributing to the base game's return, the architecture summed to **131%**. The resolution is the one this game now ships: one bonus natural (The Sonnet), one buy-only (The Tragedy). One honest overall RTP, two independently-validated buy RTPs, nothing counted twice.

THE SCATTER THAT WASN'T 1.23%. The locked scatter RTP of 1.23% was a single 100k Monte-Carlo draw that had landed $\sim 1.8\sigma$ low — the 5- and 6-ring pays are rare enough that 100k barely samples them. The closed form said 1.43%; a 2M run measured 1.4158%. Base total was therefore 40.22%, not 39.9%, and overall 96.35%, not 96.01%. A fat-tailed quantity cannot be characterised on a thin sample — the same lesson the bonus tails taught, arriving from a different direction.

THE WILD-SUBSTITUTION SPEC. A written spec described wilds as substituting for "the highest-value symbol." The implemented evaluator substitutes for whatever symbol *maximises that row's left-connected pay* — a different rule, and the correct one. It was caught before the spec could overwrite working code, and the evaluator's 300,000-row brute-force selftest still passes with zero mismatches.

6

Design Intent

The intended experience is a quiet moonlit night that occasionally opens into something enormous. The base game is calm on purpose — fireflies drift, a harp plays almost nothing, and a line win is a small warm event. That calm is what makes a rose landing feel like the world tilting.

Two Bonuses, One Engine, Opposite Souls

The Sonnet and The Tragedy share every mechanic and differ in two numbers — how often roses land, and how hot the ladder runs. Everything else is presentation doing the work those two numbers imply. The Sonnet is a blue moonlit world: white roses, fireflies, a hopeful re-spin that lands about half the time. The Tragedy is the same Verona burning: a blood moon, falling embers, black roses that smoulder with molten red in their cracks, and a re-spin that *denies you three times out of four*. The maths says "higher variance." The game says "this one will break your heart."

VOLATILITY AS THEME

The Tragedy's fat tail isn't a setting, it's the fiction. A mode that pays nothing for four rounds and then hands you the cap *is* the story of the play — brief, doomed, and worth it. The 26× cap-hit gap between the modes is Romeo and Juliet told in a distribution.

Why Additive

Multiplicative wild multipliers would make this game unshippable — three hot columns would reach six figures and the cap would be doing all the design. Additive keeps the top end legible: the player can look at the board, add the numbers, and know exactly what a full row is worth. The chase is **coverage** — get another column, add another number — which is precisely the fantasy of the art: two people reaching across a gap, one column at a time.

7

Tech & Architecture

AREA	IMPLEMENTATION
Engine / stack	TypeScript (strict) · PixiJS v8 · Vite · 1920×1080 design canvas, 960×960 board, 160px cells
RNG	mulberry32, one step per drawn cell — 36 independent draws per base board, verified against Binomial across the full tail
Math model	Trace-and-replay. The bonus is computed in one pure logic pass that owns 100% of the randomness and emits a per-spin trace; the board is a pure function of that trace and consumes zero RNG. The animation <i>cannot</i> fork the stream, so "on-screen = simulated" is structural, not tested.
Single source of truth	All weights, ladders, P_1/P_2 , pays, prices and caps live in config; the Monte-Carlo sim mirrors them exactly and the parity harness imports the real modules
Validation	2M-spin base runs · 1M-round bonus runs · independent closed-form cross-check · 300k-row line-evaluator brute-force selftest · bit-for-bit game ↔ sim parity at seed 1

AREA	IMPLEMENTATION
Info screen	Data-driven rules panel — reads live from the real constants, so the rules can never drift from the math
Audio	Procedurally synthesized SFX (numpy/scipy) + state-driven music per mode; ducked under the wild formation
Economy	Variable bet in dollars; every win — line, scatter and bonus — credits through a single shared award path

NOTES & SOURCING

Every headline figure was audited against the live code and simulation runs. Base line (38.83%), scatter (1.43%), base total (40.26%), hit frequency (26.54%) and trigger rate (1 in 127.2) come from a 2,000,000-spin run and are independently confirmed in closed form. Bonus averages ($71.12\times / 141.79\times$), distributions, coverage and cap-hit rates come from 1,000,000-round runs per mode. Buy RTPs are $E \div \text{price at the shipped}$ $75\times / 150\times$ and are declared as measured — 94.82% and 94.53%. Total game RTP (~96.2%) is composed only of the base total plus the natural Sonnet trigger; The Tragedy is buy-only and contributes nothing to it. All presentation — the fire border, rose re-spin, wild formation, embers and fireflies — is display-only over a pre-computed result and does not touch the math.