ENIGMA DARK

Securing the Shadows



Invariant Testing Engagement

Twyne

Aave V3 Integration

November, 2025

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Summary

Enigma Dark
Enigma Dark is a web3 security firm leveraging the best talent in the space to secure all kinds of blockchain protocols and decentralized apps. Our team comprises experts who have honed their skills at some of the best auditing companies in the industry. With a proven track record as highly skilled white-hats, they bring a wealth of experience and a deep understanding of the technology and the ecosystem.

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Twyne: Aave V3 Integration
Twyne is a credit delegation protocol that turns unused borrowing power into yield. It maximizes lending efficiency by delegating unused borrowing power to users that want to increase leverage or protect against liquidation.

This engagement covers the Aave V3 integration of the Twyne protocol. The invariant testing suite represents a refactored and abstracted framework designed for modularity, originally built for Twyne v1 and Euler integrations.

Engagement Overview

Over the course of 2.5 weeks, beginning October 27 2025, the Enigma Dark team conducted a continuous invariant testing engagement of the Twyne Aave Integration.

The engagement was performed by one Lead Security Researcher: vnmrtz.

The following repositories were reviewed at the specified commits:

Repository	Commit Range
0xTwyne/twyne-contracts	`a338a7e...4013035`

Scope

```
src/
├── twyne/
|   ├── AaveV3CollateralVault.sol
|   ├── CollateralVaultBase.sol
|   ├── IntermediateVault.sol
|   └── VaultManager.sol
└── TwyneFactory/
    └── TwyneFactory.sol
```

Risk Classification

Severity	Description
Critical	Vulnerabilities that lead to a loss of a significant portion of funds of the system.
High	Exploitable, causing loss or manipulation of assets or data.
Medium	Risk of future exploits that may or may not impact the smart contract execution.
Low	Minor code errors that may or may not impact the smart contract execution.
Informational	Non-critical observations or suggestions for improving code quality, readability, or best practices.

Vulnerability Summary

Severity	Count	Fixed	Acknowledged
High	0	0	0
Medium	1	0	1
Low	0	0	0
Informational	1	0	1

Invariants and Postconditions Summary

This table provides an overview of all invariants and postconditions defined in the suite specification files.

Property Types

On this invariant testing framework there exists two types of Properties:

INVARIANTS (INV)

- These are properties that should always hold true in the system
- They are implemented under `/invariants` folder

POSTCONDITIONS

- These are properties that should hold true after an action is executed
- They are implemented under `/hooks` and `/handlers` folders
- There are two types of POSTCONDITIONS:

GLOBAL POSTCONDITIONS (GPOST)

- These are properties that should always hold true after any action is executed
- They are checked in the `_checkPostConditions` function within the HookAggregator contract

HANDLER-SPECIFIC POSTCONDITIONS (HSPOST)

- These are properties that should hold true after a specific action is executed in a specific context
- They are implemented within each handler function, under the HANDLER-SPECIFIC POSTCONDITIONS section

Table Structure

- **Property ID**: The unique identifier for each property
- **Description**: The detailed explanation of what the property should ensure
- **Status**: Current testing status (PASS/FAIL/PENDING)
- **Issues**: Related issues or notes when status is not PASS

Property ID	Description	Status	Issues
INV_CV_BASE_A	The user-set LTV must be within protocol bounds	PASS	-
INV_CV_BASE_B	A collateral vault must have a non-zero borrower unless the vault has been externally liquidated and the handleExternalLiquidation function has been called	PASS	-
INV_CV_ASSETS_A	If twyne collateral vault has not been externally liquidated, its collateral asset balance must be greater or equal than totalAssetsDepositedOrReserved	PASS	-
INV_CV_ASSETS_B	If twyne collateral vault balance is less than totalAssetsDepositedOrReserved it has been externally liquidated but handleExternalLiquidation has not been called	PASS	-
INV_CV_LTV_A	Twyne LTV >= Ext LTV	PASS	-
INV_CV_DEBT_A	If maxRepay() returns non-zero, there must be external debt	PASS	-
INV_CV_LQ_A	If the collateralVault position is liquidatable it must be liquidatable on twyne	PASS	-
INV_CV_NR_A	balanceOf(borrower) must never revert	PASS	-
INV_CV_NR_B	maxRepay must never revert	PASS	-
INV_CV_NR_C	maxRelease must never revert	PASS	-
INV_CV_NR_D	canLiquidate must never revert	PASS	-
INV_CV_NR_E	isExternallyLiquidated must never revert	PASS	-

Property ID	Description	Status	Issues
HSPOST_CV_BASE_A	After rebalancing, the vault should not become liquidatable if it wasn't before	PASS	-
HSPOST_CV_BASE_B	Rebalancing should never decrease user's actual collateral amount	PASS	-
HSPOST_CV_BASE_C	After rebalancing, the amount of excess credit should be 0	PASS	-
HSPOST_CV_ASSETS_A	After depositing, totalAssetsDepositedOrReserved must increase at least by deposit amount	PASS	-
HSPOST_CV_ASSETS_B	After withdrawing, totalAssetsDepositedOrReserved must decrease at least by withdrawn amount	PASS	-
HSPOST_CV_ASSETS_C	After depositing, vault balance must increase at least by deposit amount	PASS	-
HSPOST_CV_ASSETS_D	After withdrawing, vault balance must decrease at least by withdrawn amount	PASS	-
HSPOST_CV_DEBT_A	After deposit, maxRepay (credit) must increase	PASS	-
HSPOST_CV_DEBT_B	After withdraw, maxRepay (credit) must decrease	PASS	-
HSPOST_CV_DEBT_C	After borrowing, the correct amount of debt on twyne collateral vault must be created	PASS	-

Property ID	Description	Status	Issues
HSPOST_CV_DEBT_D	After repaying, the correct amount of debt on twyne collateral vault must be repaid	PASS	I-01
HSPOST_CV_DEBT_G	After borrowing, the correct amount of debt assets must be transferred to receiver	PASS	-
HSPOST_CV_DEBT_H	After repaying, the correct amount of debt assets must be transferred from the borrower	PASS	-
HSPOST_CV_DEBT_I	A borrower should always be able to withdraw all if there is no outstanding debt and the vault is not externally liquidated	PASS	-
HSPOST_CV_DEBT_J	A user with enough funds can always repay debt in full	PASS	-
GPOST_CV_HEALTH_A	Only a deposit, depositUnderlying, repay and handleExternalLiquidation, can leave it in an unhealthy state, and only if the borrower is already in an unhealthy state	PASS	-
GPOST_CV_HEALTH_B	Only liquidations can deteriorate health score of an already unhealthy borrower	PASS	-
GPOST_CV_HEALTH_C	After any action against the twyne collateral vault, excess credit should never be negative	PASS	-
GPOST_CV_HEALTH_D	Borrower position against twyne collateral vault should not not be liquidatable after any action	PASS	-
GPOST_CV_HEALTH_E	Unhealthy borrowers can not borrow	PASS	-

Property ID	Description	Status	Issues
GPOST_CV_SIPHON_A	totalAssetsDepositedOrReserved - maxRelease() should never increase without explicit user deposits	PASS	-
HSPOST_CV_LQ_A	Liquidation can only succeed if violator is unhealthy	PASS	-
HSPOST_CV_LQ_B	External liquidation should only be possible if the underlying position has been liquidated and vault balance < totalAssetsDepositedOrReserved	PASS	-
HSPOST_CV_LQ_C	If the underlying position has been liquidated, external liquidation should always succeed and vault balance < totalAssetsDepositedOrReserved	PASS	-
HSPOST_CV_LQ_E	After handleExternalLiquidation, totalAssetsDepositedOrReserved should be 0	PASS	-
HSPOST_CV_LQ_F	After handleExternalLiquidation, maxRepay() should return 0	PASS	-
HSPOST_CV_NR_B	If canRebalance returns a non-zero value, rebalance must not revert the vault is not liquidatable	PASS	-
HSPOST_CV_NR_D	repay(maxRepay) must never revert	PASS	-

Summary

- **Total Properties**: 34
- **Invariants (INV)**: 12
- **Global Postconditions (GPOST)**: 6
- **Handler-Specific Postconditions (HSPOST)**: 16
- **Status Distribution**:
    - PENDING: 0
    - PASS: 34
    - FAIL: 0

Categories

Base Functionality

- User-set LTV bounds validation
- Borrower existence validation
- Rebalancing effects on liquidation status and collateral amounts

Asset Management

- Vault balance vs totalAssetsDepositedOrReserved consistency
- Proper tracking of deposits and withdrawals
- Collateral value preservation

Loan-to-Value (LTV) Ratios

- Relationship between Twyne LTV and external LTV

Debt Management

- Debt existence validation
- Credit tracking and excess credit bounds
- Borrowing and repayment correctness
- Asset transfer validation

Health and Liquidation

- Position health maintenance
- Liquidation conditions and effects
- External liquidation handling
- Borrower state after liquidation

Non-Revert Guarantees

- View functions must never revert
- Critical operations must succeed under valid conditions

Siphoning Protection

- Prevention of unauthorized asset extraction

Status Definitions

- **PENDING**: Property has not been tested yet or testing is in progress
- **PASS**: Property passes all tests and behaves as expected
- **FAIL**: Property fails tests and requires attention

Resolution Options (for FAIL status properties)

- **FIXED**: The underlying issue has been resolved by the protocol team, property should pass on re-testing
- **ACKNOWLEDGED**: The issue has been reviewed and acknowledged by the protocol team as acceptable risk/design decision

*Note: Detailed explanations for all failing properties and their related issues can be found in the **Findings** section below.*

Testing Workflow

1. Properties start as **PENDING** before testing
2. After initial testing, properties become **PASS** or **FAIL**
3. For **FAIL** status properties, the protocol team responds with either:
    - **FIXED**: Issue gets resolved (property should pass on re-testing)
    - **ACKNOWLEDGED**: Issue is accepted as acceptable risk/design decision

Findings

Index	Issue Title	Status
M-01	eMode category cannot be updated after initialization	Acknowledged
I-01	Repayment amount may be 1 wei less than expected due to Aave rounding	Acknowledged

Detailed Findings

High Risk

No issues found.

Medium Risk

M-01 - eMode category cannot be updated after initialization

Severity: Medium Risk

Context:

- AaveV3CollateralVault.sol#L59-L89

Technical Details:
Once an AaveV3CollateralVault is initialized, the categoryId (eMode category) is set permanently and cannot be changed. There is no function to update the eMode category after initialization.

- If Aave governance changes eMode parameters (higher LTV in a new category, or deprecates the current category), users cannot migrate to benefit from better parameters without creating an entirely new vault.
- If the current eMode category is disabled or modified unfavorably by Aave governance, the collateral vault is stuck with potentially worse liquidation thresholds.

Impact:
While this does not directly lead to loss of funds, it creates significant operational friction and capital inefficiency for users. In scenarios where Aave governance modifies eMode parameters unfavourably, users could face unexpected liquidation risk or be forced to pay substantial gas costs and slippage to migrate their positions to new vaults.

Recommendation:
Add a function to allow the borrower to update the eMode category with proper safety checks.

Developer Response:
Acknowledged.

Low Risk

No issues found.

Informational

I-01 - Repayment amount may be 1 wei less than expected due to Aave rounding

Severity: Informational

Context:

- AaveV3CollateralVault.sol
- Related postcondition: HSPOST_CV_DEBT_D

Technical Details:
The Aave protocol uses asymmetric rounding in its aToken balance calculations:

- `balanceOf` uses `rayMulCeil` (rounds UP)
- `burn` uses `rayDivFloor` (rounds DOWN)

At dust amounts with interest accrual, this causes the actual debt reduction to be 1 wei less than the repayment amount. When a user repays X tokens, the debt may only decrease by X-1 due to this rounding asymmetry.

PoC:

```
test_replay_13_repayCV_aave

- Postcondition: HSPOST_CV_DEBT_D - After repaying, the correct amount of
debt on twyne collateral vault must be repaid
- Error: Invalid: 3!=4
- Details: Left: 3, Right: 2 + 2 = 4, Delta: 1 wei
- Context: User paid 2, Aave credited 1
```

Recommendation:
Add a 1 wei tolerance to `HSPOST_CV_DEBT_D` postcondition assertion to account for Aave's rounding behavior.

Developer Response:
Acknowledged. A 1 wei tolerance was added to the postcondition assertions to account for this rounding asymmetry. Invariant successfully passed after the assertion was adjusted.

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