SMART CONTRACT AUDIT REPORT

for

Enzo Finance

Prepared By: Xiaomi Huang

PeckShield

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Contact

For more information about this document and its contents, please contact PeckShield Inc.

Name	Xiaomi Huang
Phone	+86 183 5897 7782
Email	contact@peckshield.com

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1 | Introduction

Given the opportunity to review the design document and related smart contract source code of the Enzo Finance protocol, we outline in the report our systematic approach to evaluate potential security issues in the smart contract implementation, expose possible semantic inconsistencies between smart contract code and design document, and provide additional suggestions or recommendations for improvement. Our results show that the given version of smart contracts can be further improved due to the presence of several issues related to either security or performance. This document outlines our audit results.

1.1 About Enzo

Enzo is an innovative non-custodial money market protocol. Built upon the popular CompoundV2 protocol, Enzo allows users to lend any supported assets and leverage their capital to borrow other supported assets. The platform allows users to have complete control over their funds and offers competitive interest rates without any intermediaries involved. The basic information of the audited protocol is as follows:

Table 1.1: Basic Information of The Blastway Protocol

Item	Description
Name	Enzo
Type	Ethereum Smart Contract
Platform	Solidity
Audit Method	Whitebox
Latest Audit Report	April 3, 2024

In the following, we show the Git repository of reviewed files and the commit hash value used in this audit.

- https://github.com/EnzoFinance/enzo-protocol.git (9d6d50a)

And this is the commit ID after all fixes for the issues found in the audit have been checked in:

- https://github.com/EnzoFinance/enzo-protocol.git (04dde76)

1.2 About PeckShield

PeckShield Inc. [11] is a leading blockchain security company with the goal of elevating the security, privacy, and usability of current blockchain ecosystems by offering top-notch, industry-leading services and products (including the service of smart contract auditing). We are reachable at Telegram (https://t.me/peckshield), Twitter (http://twitter.com/peckshield), or Email (contact@peckshield.com).

Table 1.2: Vulnerability Severity Classification

Impact \ Likelihood	*High*	*Medium*	*Low*
High	Critical	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low

1.3 Methodology

To standardize the evaluation, we define the following terminology based on OWASP Risk Rating Methodology [10]:

- Likelihood represents how likely a particular vulnerability is to be uncovered and exploited in the wild;
- Impact measures the technical loss and business damage of a successful attack;
- Severity demonstrates the overall criticality of the risk.

Likelihood and impact are categorized into three ratings: *H*, *M* and *L*, i.e., *high*, *medium* and *low* respectively. Severity is determined by likelihood and impact and can be classified into four categories accordingly, i.e., *Critical*, *High*, *Medium*, *Low* shown in Table 1.2.

To evaluate the risk, we go through a list of check items and each would be labeled with a severity category. For one check item, if our tool or analysis does not identify any issue, the

Table 1.3: The Full List of Check Items

Category	Check Item
Basic Coding Bugs	Constructor Mismatch
	Ownership Takeover
	Redundant Fallback Function
	Overflows & Underflows
	Reentrancy
	Money-Giving Bug
	Blackhole
	Unauthorized Self-Destruct
	Revert DoS
	Unchecked External Call
	Gasless Send
	Send Instead Of Transfer
	Costly Loop
	(Unsafe) Use Of Untrusted Libraries
	(Unsafe) Use Of Predictable Variables
	Transaction Ordering Dependence
	Deprecated Uses
Semantic Consistency Checks	Semantic Consistency Checks
Advanced DeFi Scrutiny	Business Logics Review
	Functionality Checks
	Authentication Management
	Access Control & Authorization
	Oracle Security
	Digital Asset Escrow
	Kill-Switch Mechanism
	Operation Trails & Event Generation
	ERC20 Idiosyncrasies Handling
	Frontend-Contract Integration
	Deployment Consistency
	Holistic Risk Management
Additional Recommendations	Avoiding Use of Variadic Byte Array
	Using Fixed Compiler Version
	Making Visibility Level Explicit
	Making Type Inference Explicit
	Adhering To Function Declaration Strictly
	Following Other Best Practices

contract is considered safe regarding the check item. For any discovered issue, we might further deploy contracts on our private testnet and run tests to confirm the findings. If necessary, we would additionally build a PoC to demonstrate the possibility of exploitation. The concrete list of check items is shown in Table 1.3.

In particular, we perform the audit according to the following procedure:

- Basic Coding Bugs: We first statically analyze given smart contracts with our proprietary static code analyzer for known coding bugs, and then manually verify (reject or confirm) all the issues found by our tool.
- Semantic Consistency Checks: We then manually check the logic of implemented smart contracts and compare with the description in the white paper.
- Advanced DeFi Scrutiny: We further review business logics, examine system operations, and place DeFi-related aspects under scrutiny to uncover possible pitfalls and/or bugs.
- Additional Recommendations: We also provide additional suggestions regarding the coding and development of smart contracts from the perspective of proven programming practices.

To better describe each issue we identified, we categorize the findings with Common Weakness Enumeration (CWE-699) [9], which is a community-developed list of software weakness types to better delineate and organize weaknesses around concepts frequently encountered in software development. Though some categories used in CWE-699 may not be relevant in smart contracts, we use the CWE categories in Table 1.4 to classify our findings.

1.4 Disclaimer

Note that this security audit is not designed to replace functional tests required before any software release, and does not give any warranties on finding all possible security issues of the given smart contract(s) or blockchain software, i.e., the evaluation result does not guarantee the nonexistence of any further findings of security issues. As one audit-based assessment cannot be considered comprehensive, we always recommend proceeding with several independent audits and a public bug bounty program to ensure the security of smart contract(s). Last but not least, this security audit should not be used as investment advice.

Table 1.4: Common Weakness Enumeration (CWE) Classifications Used in This Audit

Category	Summary
Configuration	Weaknesses in this category are typically introduced during the configuration of the software.
Data Processing Issues	Weaknesses in this category are typically found in functionality that processes data.
Numeric Errors	Weaknesses in this category are related to improper calculation or conversion of numbers.
Security Features	Weaknesses in this category are concerned with topics like authentication, access control, confidentiality, cryptography, and privilege management. (Software security is not security software.)
Time and State	Weaknesses in this category are related to the improper management of time and state in an environment that supports simultaneous or near-simultaneous computation by multiple systems, processes, or threads.
Error Conditions, Return Values, Status Codes	Weaknesses in this category include weaknesses that occur if a function does not generate the correct return/status code, or if the application does not handle all possible return/status codes that could be generated by a function.
Resource Management	Weaknesses in this category are related to improper management of system resources.
Behavioral Issues	Weaknesses in this category are related to unexpected behaviors from code that an application uses.
Business Logics	Weaknesses in this category identify some of the underlying problems that commonly allow attackers to manipulate the business logic of an application. Errors in business logic can be devastating to an entire application.
Initialization and Cleanup	Weaknesses in this category occur in behaviors that are used for initialization and breakdown.
Arguments and Parameters	Weaknesses in this category are related to improper use of arguments or parameters within function calls.
Expression Issues	Weaknesses in this category are related to incorrectly written expressions within code.
Coding Practices	Weaknesses in this category are related to coding practices that are deemed unsafe and increase the chances that an exploitable vulnerability will be present in the application. They may not directly introduce a vulnerability, but indicate the product has not been carefully developed or maintained.

2 Findings

2.1 Summary

Here is a summary of our findings after analyzing the `Enzo` implementation. During the first phase of our audit, we study the smart contract source code and run our in-house static code analyzer through the codebase. The purpose here is to statically identify known coding bugs, and then manually verify (reject or confirm) issues reported by our tool. We further manually review business logics, examine system operations, and place DeFi-related aspects under scrutiny to uncover possible pitfalls and/or bugs.

Severity	# of Findings	
Critical	0	
High	0	
Medium	2	🟦🟦
Low	2	🟦🟦
Informational	0	
Total	4	

We have so far identified a list of potential issues: some of them involve subtle corner cases that might not be previously thought of, while others refer to unusual interactions among multiple contracts. For each uncovered issue, we have therefore developed test cases for reasoning, reproduction, and/or verification. After further analysis and internal discussion, we determined a few issues of varying severities that need to be brought up and paid more attention to, which are categorized in the above table. More information can be found in the next subsection, and the detailed discussions of each of them are in Section 3.

2.2 Key Findings

Overall, these smart contracts are well-designed and engineered, though the implementation can be improved by resolving the identified issues (shown in Table 2.1), including 2 medium-severity vulnerabilities and 2 low-severity vulnerabilities.

Table 2.1: Key Enzo Finance Audit Findings

ID	Severity	Title	Category	Status
PVE-001	Low	Market Funds Availability With Dual-Entry Tokens	Coding Practices	Resolved
PVE-002	Medium	Trust Issue of Admin Keys	Security Features	Mitigated
PVE-003	Low	Non ERC20-Compliance of CToken	Coding Practices	Confirmed
PVE-004	Medium	Empty Market Avoidance With MINIMUM_LIQUIDITY Enforcement	Numeric Errors	Resolved

Besides recommending specific countermeasures to mitigate these issues, we also emphasize that it is always important to develop necessary risk-control mechanisms and make contingency plans, which may need to be exercised before the mainnet deployment. The risk-control mechanisms need to kick in at the very moment when the contracts are being deployed in mainnet. Please refer to Section 3 for details.

3 Detailed Results

3.1 Market Funds Availability With Dual-Entry Tokens

- ID: PVE-001
- Severity: Low
- Likelihood: Low
- Impact: Low
- Targets: CErc20
- Category: Business Logic [7]
- CWE subcategory: CWE-841 [4]

Description

The Enzo protocol follows a similar architectural design of Compound with a central Enzotroller contract and various money markets. While examining current money market logic, we notice the presence of a helper routine sweepToken(), which needs to be revisited.

In the following, we show the implementation of this specific routine sweepToken(). This routine has a straightforward logic in recovering accidental ERC20 transfers to this market contract. However, it does not take into consideration the presence of so-called dual-entry tokens. For example, the TUSD token used to have two different contracts that both interact with the same balances. (These two contracts are 0x0000000000085d4780b73119b644ae5ecd22b376 and 0x8dd5fbce2f6a956c3022ba3663759011dd51e73e .) From a normal user's perspective, interacting with one of the contracts affects the balances of both. In most cases, this will not be an issue. However, in this specific case of sweepToken(), it will cause a griefing issue to making the funds not available.

```
    function sweepToken(EIP20NonStandardInterface token) public {
        require(address(token) != underlying, "can not sweep underlying token");
        uint256 balance = token.balanceOf(address(this));
        token.transfer(admin, balance);
    }
```

Listing 3.1: CToken::sweepToken()

Recommendation Properly revisit the above logic by validating the caller to be money market admin only.

Status This issue has been fixed in this commit: `04dde76`.

3.2 Trust Issue of Admin Keys

- ID: PVE-002
- Severity: Medium
- Likelihood: Medium
- Impact: Medium
- Target: `Multiple Contracts`
- Category: Security Features [5]
- CWE subcategory: CWE-287 [3]

Description

In the `Enzo` protocol, there is a privileged `owner` account that plays a critical role in governing and regulating the system-wide operations (e.g., parameter setting and marketing adjustment). It also has the privilege to control or govern the flow of assets managed by this protocol. Our analysis shows that the privileged account needs to be scrutinized. In the following, we examine the privileged account and their related privileged accesses in current contracts.

```
    function _setMarketSupplyCaps(address[] calldata cTokens, uint[] calldata
        newSupplyCaps) external onlySafetyGuardian {
        uint numMarkets = cTokens.length;
        uint numSupplyCaps = newSupplyCaps.length;

        require(numMarkets != 0 && numMarkets == numSupplyCaps, "invalid input");

        for(uint i = 0; i < numMarkets; i++) {
            marketsCap[cTokens[i]].supplyCap = newSupplyCaps[i];
            emit NewSupplyCap(cTokens[i], newSupplyCaps[i]);
        }
    }
    /**
     * @notice Sets whitelisted protocol's credit limit
     * @param protocol The address of the protocol
     * @param creditLimit The credit limit
     */
    function _setCreditLimit(address protocol, uint creditLimit) public onlyOwner {
        require(isContract(protocol), "contract required");
        require(creditLimits[protocol] != creditLimit, "no change");

        creditLimits[protocol] = creditLimit;
        emit CreditLimitChanged(protocol, creditLimit);
    }

    function _setCompToken(address _compToken) public onlyOwner {
        address oldCompToken = compToken;
        compToken = _compToken;
        emit NewCompToken(oldCompToken, compToken);
    }

    function _setSafetyVault(address _safetyVault) public onlyOwner {
        address oldSafetyVault = safetyVault;
        safetyVault = _safetyVault;
        emit NewSafetyVault(oldSafetyVault, safetyVault);
    }

    function _setSafetyVaultRatio(uint _safetyVaultRatio) public onlySafetyGuardian {
        require(_safetyVaultRatio < 1e18, "!safetyVaultRatio");

        uint oldSafetyVaultRatio = safetyVaultRatio;
        safetyVaultRatio = _safetyVaultRatio;
        emit NewSafetyVaultRatio(oldSafetyVaultRatio, safetyVaultRatio);
    }

    function _setPendingSafetyGuardian(address payable newPendingSafetyGuardian)
        external onlyOwner {
        address oldPendingSafetyGuardian = pendingSafetyGuardian;
        pendingSafetyGuardian = newPendingSafetyGuardian;

        emit NewPendingSafetyGuardian(oldPendingSafetyGuardian, newPendingSafetyGuardian
            );
    }
```

Listing 3.2: Example Privileged Operations in `EnzoConfig`

Apparently, if the privileged `owner` account is a plain EOA account, this may be worrisome and pose counter-party risk to the exchange users. Note that a multi-sig account could greatly alleviate this concern, though it is still far from perfect. Specifically, a better approach is to eliminate the administration key concern by transferring the role to a community-governed DAO. In the meantime, a timelock-based mechanism can also be considered as mitigation.

Moreover, it should be noted that current contracts have the support of being deployed behind a proxy. And there is a need to properly manage the proxy-admin privileges as they fall in this trust issue as well.

Recommendation Promptly transfer the privileged account to the intended `DAO`-like governance contract. All changed to privileged operations may need to be mediated with necessary timelocks. Eventually, activate the normal on-chain community-based governance life-cycle and ensure the intended trustless nature and high-quality distributed governance.

Status This issue has been mitigated as the team has confirmed that these privileged functions are now managed by a trusted multi-sig account, not a plain EOA account.

3.3 Non ERC20-Compliance Of CToken

- ID: PVE-003
- Severity: Low
- Likelihood: Medium
- Impact: Low
- Target: `CToken`
- Category: Coding Practices [6]
- CWE subcategory: CWE-1126 [1]

Description

Each asset supported by the `Enzo` protocol is integrated through a so-called `CToken` contract, which is an ERC20 compliant representation of balances supplied to the protocol. By minting `CToken`, users can earn interest through the `CToken`'s exchange rate, which increases in value relative to the underlying asset, and further gains the ability to use `CToken` as collateral. In the following, we examine the ERC20 compliance of these `CToken`.

Table 3.1: Basic `View-Only` Functions Defined in The ERC20 Specification

Item	Description	Status
name()	Is declared as a public view function	✓
	Returns a string, for example "Tether USD"	✓
symbol()	Is declared as a public view function	✓
	Returns the symbol by which the token contract should be known, for example "USDT". It is usually 3 or 4 characters in length	✓
decimals()	Is declared as a public view function	✓
	Returns decimals, which refers to how divisible a token can be, from 0 (not at all divisible) to 18 (pretty much continuous) and even higher if required	✓
totalSupply()	Is declared as a public view function	✓
	Returns the number of total supplied tokens, including the total minted tokens (minus the total burned tokens) ever since the deployment	✓
balanceOf()	Is declared as a public view function	✓
	Anyone can query any address' balance, as all data on the blockchain is public	✓
allowance()	Is declared as a public view function	✓
	Returns the amount which the spender is still allowed to withdraw from the owner	✓

The ERC20 specification defines a list of API functions (and relevant events) that each token contract is expected to implement (and emit). The failure to meet these requirements means the token contract cannot be considered to be ERC20-compliant. Naturally, as part of our audit, we examine the list of API functions defined by the ERC20 specification and validate whether there exist any inconsistency or incompatibility in the implementation or the inherent business logic of the audited contract(s).

Table 3.2: Key `State-Changing` Functions Defined in The ERC20 Specification

Item	Description	Status
transfer()	Is declared as a public function	✓
	Returns a boolean value which accurately reflects the token transfer status	✓
	Reverts if the caller does not have enough tokens to spend	×
	Allows zero amount transfers	✓
	Emits Transfer() event when tokens are transferred successfully (include 0 amount transfers)	✓
	Reverts while transferring to zero address	✓
transferFrom()	Is declared as a public function	✓
	Returns a boolean value which accurately reflects the token transfer status	✓
	Reverts if the spender does not have enough token allowances to spend	×
	Updates the spender's token allowances when tokens are transferred successfully	✓
	Reverts if the from address does not have enough tokens to spend	×
	Allows zero amount transfers	✓
	Emits Transfer() event when tokens are transferred successfully (include 0 amount transfers)	✓
	Reverts while transferring from zero address	✓
	Reverts while transferring to zero address	✓
approve()	Is declared as a public function	✓
	Returns a boolean value which accurately reflects the token approval status	✓
	Emits Approval() event when tokens are approved successfully	✓
	Reverts while approving to zero address	✓
Transfer() event	Is emitted when tokens are transferred, including zero value transfers	✓
	Is emitted with the from address set to $address(0x0)$ when new tokens are generated	✓
Approval() event	Is emitted on any successful call to approve()	✓

Our analysis shows that there are several ERC20 inconsistency or incompatibility issues found in the `CToken` contract. Specifically, the current `transfer()` function simply returns the related error code if the sender does not have sufficient balance to spend. A similar issue is also present in the `transferFrom()` function that does not revert when the sender does not have the sufficient balance or the message sender does not have the enough allowance.

In the surrounding two tables, we outline the respective list of basic `view-only` functions (Table 3.1) and key `state-changing` functions (Table 3.2) according to the widely-adopted ERC20 specification. In addition, we perform a further examination on certain features that are permitted by the ERC20 specification or even further extended in follow-up refinements and enhancements (e.g., ERC777/ERC2222), but not required for implementation. These features are generally helpful, but may also impact or bring certain incompatibility with current DeFi protocols. Therefore, we consider it is important to highlight them as well. This list is shown in Table 3.3.

Table 3.3: Additional `Opt-in` Features Examined in Our Audit

Feature	Description	Opt-in
Deflationary	Part of the tokens are burned or transferred as fee while on transfer()/transferFrom() calls	—
Rebasing	The balanceOf() function returns a re-based balance instead of the actual stored amount of tokens owned by the specific address	—
Pausable	The token contract allows the owner or privileged users to pause the token transfers and other operations	✓
Blacklistable	The token contract allows the owner or privileged users to blacklist a specific address such that token transfers and other operations related to that address are prohibited	—
Mintable	The token contract allows the owner or privileged users to mint tokens to a specific address	✓
Burnable	The token contract allows the owner or privileged users to burn tokens of a specific address	✓

Recommendation Revise the `CToken` implementation to ensure its ERC20-compliance.

Status The issue has been confirmed.

3.4 Empty Market Avoidance With MINIMUM_LIQUIDITY Enforcement

- ID: PVE-004
- Severity: Medium
- Likelihood: Medium
- Impact: High
- Target: `CToken`, `EToken`
- Category: Numeric Errors [8]
- CWE subcategory: CWE-190 [2]

Description

The `Enzo` protocol is in essence an over-collateralized lending pool that has the lending functionality and supports a number of normal lending functionalities for supplying and borrowing users, i.e., mint()/redeem() and borrow()/repay(). While reviewing the redeem logic, we notice the current implementation has a precision issue that has been reflected in a recent HundredFinance hack.

To elaborate, we show below the related redeemFresh() routine. As the name indicates, this routine is designed to redeems CTokens in exchange for the underlying asset. When the user indicates the underlying asset amount (via redeemUnderlying()), the respective redeemTokens is computed as redeemTokens = div_(redeemAmountIn, exchangeRate) (line 639). Unfortunately, the current approach may unintentionally introduce a precision issue by computing the redeemTokens amount against the protocol. Specifically, the resulting flooring-based division introduces a precision loss, which may be just a small number but plays a critical role when certain boundary conditions are met – as demonstrated in the recent HundredFinance hack: https://blog.hundred.finance/15-04-23-hundred-finance-hack-post-mortem-d895b618cf33.

```
519     function redeemFresh(address payable redeemer, uint redeemTokensIn, uint
            redeemAmountIn) internal returns (uint) {
520         require(redeemTokensIn == 0  redeemAmountIn == 0, "zero");

522         RedeemLocalVars memory vars;

524         /* exchangeRate = invoke Exchange Rate Stored() */
525         vars.exchangeRateMantissa = exchangeRateStoredInternal();

527         /* If redeemTokensIn > 0: */
528         if (redeemTokensIn > 0) {
529             /*
530              * We calculate the exchange rate and the amount of underlying to be
                   redeemed:
531              *  redeemTokens = redeemTokensIn
532              *  redeemAmount = redeemTokensIn x exchangeRateCurrent
533              */
534             vars.redeemTokens = redeemTokensIn;

536             vars.redeemAmount = mul_ScalarTruncate(Exp({mantissa: vars.
                    exchangeRateMantissa}), redeemTokensIn);
537         } else {
538             /*
539              * We get the current exchange rate and calculate the amount to be redeemed:
540              *  redeemTokens = redeemAmountIn / exchangeRate
541              *  redeemAmount = redeemAmountIn
542              */

544             vars.redeemTokens = div_ScalarByExpTruncate(redeemAmountIn, Exp({mantissa:
                    vars.exchangeRateMantissa}));

546             vars.redeemAmount = redeemAmountIn;
547         }

549         /* Fail if redeem not allowed */
550         uint allowed = comptroller.redeemAllowed(address(this), redeemer, vars.
                redeemTokens);
        if (allowed != 0) {
            return failOpaque(Error.COMPTROLLER_REJECTION, FailureInfo.
                REDEEM_COMPTROLLER_REJECTION, allowed);
        }
        ...
    }
```

Listing 3.3: `CToken::redeemFresh()`

Recommendation Properly revise the above routine to ensure the precision loss needs to be computed in favor of the protocol, instead of the user. In particular, we need to ensure that markets are never empty by minting small `CToken` balances at the time of market creation so that we can prevent the rounding error being used maliciously. A deposit as small as 1 wei is sufficient.

Status The issue has been resolved as the team blocks the donation approach to manipulate the exchange rate. In the meantime, the team will exercise extra care in adding new markets by ensuring that they are never empty by minting small `CToken` balances at the time of market creation, which prevents the rounding error being used maliciously.

4 Conclusion

In this audit, we have analyzed the design and implementation of the `Enzo` protocol, which is an innovative non-custodial money market protocol. Built upon the popular `CompoundV2` protocol, `Enzo` allows users to lend any supported assets and leverage their capital to borrow other supported assets. The platform allows users to have complete control over their funds and offers competitive interest rates without any intermediaries involved. During the audit, we notice that the current code base is well organized and those identified issues are promptly confirmed and fixed.

Meanwhile, we need to emphasize that smart contracts as a whole are still in an early, but exciting stage of development. To improve this report, we greatly appreciate any constructive feedbacks or suggestions, on our methodology, audit findings, or potential gaps in scope/coverage.

References

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[4] MITRE. CWE-841: Improper Enforcement of Behavioral Workflow. https://cwe.mitre.org/data/definitions/841.html.

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