Privilege Escalation and Arbitrary Page Tampering in Cloudflare Pages (English translation)

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Content (translated into English)

Machine translation of `2023-blog-ryotak-net-cloudflare-pages.md`, which holds the source's own words. Code, payloads, type names, URLs and CVE identifiers were masked before translating and restored after, so they are byte-identical to the original.

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Privilege Escalation and Arbitrary Page Tampering in Cloudflare Pages

* *2023-12-23* * 5710 characters **CloudflareVulnerabilityPython

You can read about these vulnerabilities in English at https://ec0.io/post/hacking-cloudflare-pages-part-2/

Disclaimer

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Note that this article was written in 2022, and some of its content may differ from the situation at the time of publication.

Summary

I worked with James Hebden and Sean Yeoh to discover multiple vulnerabilities in Cloudflare Pages. These vulnerabilities made it possible to obtain root privileges in the Cloudflare Pages build environment, steal scripts deployed using the Cloudflare Pages Functions feature, and tamper with other people's pages built on Cloudflare Pages.

What Is Cloudflare Pages?

Cloudflare Pages is a JAMstack platform provided by Cloudflare and is primarily used to host static sites. By using a feature that was in beta when these vulnerabilities were reported, it can also integrate with Cloudflare Workers and execute server-side code.

Reason for the Investigation

While gathering security-related information, I came across an article titled Cloudflare Pages, part 1: The fellowship of the secret. I found the article extremely interesting, so I decided to investigate Cloudflare Pages in the hope of finding vulnerabilities myself.

Research Environment

Cloudflare Pages provides a feature that generates static sites using commands specified by users. As explained in the blog post above, the environment in which these commands run is inside Kubernetes, and the builds are run by a `buildbot` user with highly restricted privileges. As a result, the investigation has to begin in a situation where useful information1 cannot be obtained.

Beginning the Investigation

Because I wanted to find a container escape like the one in the aforementioned article, or a similar vulnerability, I decided to begin by looking for a way out of the current restricted environment.

[image: List of processes running in the Cloudflare Pages build environment] As the process list above shows, the process that executes user-specified commands is one whose privileges were dropped by `/opt/pages/build_tool/main.py` (hereafter `build_tool`) using `sudo`. Because `build_tool` itself was running with root privileges, I tried to determine whether a vulnerability in `build_tool` could be used for privilege escalation, but with the current privileges I could not read the `build_tool` file.

I therefore made reading the contents of `build_tool` my first objective.

Arbitrary File Read

Files generated by a user-specified command are read in some way after the command finishes and deployed to Cloudflare's network.

Because the subsequent processing is performed by a process running as root, I suspected that root was reading the files. I therefore wondered whether placing symbolic links in place of the built files might make it possible to read arbitrary files on the system.

As a test, I replaced index.html with a symbolic link and attempted to read the contents of `/etc/shadow`, but index.html was not included in the deployed website, suggesting that simply placing a symbolic link would not work.

While investigating Cloudflare Pages features in greater detail, I found a feature called `Redirects`. This feature lets users customize redirect rules by including a file called `_redirects` in the website, and the file appeared to be parsed after the user-specified command was executed.

[image: Explanation of Redirects in the Cloudflare Pages documentation]

Source: Cloudflare Docs

Unlike ordinary files, it is not published on the website, so I thought there might be a difference in the process used to parse it. When I replaced this file with a symbolic link, after deployment I was able to read the contents of `/etc/shadow`, which the `buildbot` user did not have permission to read, from the dashboard.

[image: /etc/shadow displayed in the Cloudflare dashboard]

Collaboration

By the time I found a way to read arbitrary files from the build environment, it was nearly 9 p.m., and only about one day remained for vulnerability research.2 It did not seem realistic to find a privilege escalation alone and then search for further vulnerabilities, so I decided to ask the two authors of the article mentioned at the beginning of this post to collaborate.

[image: Asking the two authors of the article to collaborate on Twitter]

James replied immediately, and the three of us agreed to work together to search for vulnerabilities.

[image: James's reply readily agreeing to collaborate]

Reading the build_tool Code

After James replied, the two of us decided to look for a way to escalate privileges until Sean arrived.

Using the arbitrary file-read vulnerability described above, we downloaded the code for `build_tool` and read it to look for vulnerabilities, but there did not appear to be a simple command injection like those James and Sean had previously found.

After we had spent some time chatting and looking over the code together, the following code caught our attention.

```
    version = [env_var['value'] for env_var in env_vars if env_var['key'] == 'PAGES_WRANGLER_VERSION'][0]
    print_line(f'Overriding wrangler version to {version}...', logs)

    subprocess.run(['npm', 'install', f'wrangler@{version}'], cwd=WRANGLER_DIR, check=True, capture_output=True)

    print_line('wrangler version override complete!', logs)
```

This code uses `npm install` to change the version of wrangler based on a user-specified environment variable called `PAGES_WRANGLER_VERSION`. We realized that there might be some way to make it install a package other than wrangler, such as by putting a string containing `@` in `PAGES_WRANGLER_VERSION`, so we decided to read the npm code.

Privilege Escalation via npm

After reading the npm code, we learned that `npm install`, like `package.json` and similar commands, downloads a tarball from a specified URL instead of the npm registry when a URL is provided where the version would normally be specified.3

For example, when the command `npm install wrangler@https://example.com/example.tgz` is run, instead of trying to install version `https://example.com/example.tgz` of wrangler, it downloads a tarball from `https://example.com/example.tgz` and treats it as wrangler.

Later in the process, the installed wrangler is executed as shown below. Because this takes place on `build_tool`, which runs with root privileges, it was possible to take root privileges by installing and executing a crafted wrangler package.

```
    cmd = [
        './node_modules/.bin/wrangler2',
        'pages',
        'functions',
        'build',
        "--outfile",
        constants.OUTPUT_WORKER_PATH,
        "--output-config-path",
        constants.USER_WORKER_DERIVED_CONFIG_PATH,
        '--build-output-directory',
        output_dir,
        functions_dir
    ]

    with subprocess.Popen(cmd, **plinko_args) as proc:
```

Using this, we were able to obtain root privileges in the build environment and conduct further research.

[image: Celebrating on Discord after successfully escalating privileges via npm]

The Next Day

By the time we succeeded in obtaining root privileges, it was already past midnight, so we went to sleep for the time being and prepared for the next day.

When I woke up the next morning, Sean had joined us, so the three of us resumed the investigation. As our basic policy, we set the goal of finding a vulnerability that would allow us to access other users' data and began investigating.

We investigated every corner of the build environment to determine whether a container escape was possible, but found no vulnerability that appeared usable for a container escape. We therefore changed direction and decided to examine the process used to deploy the built site from the build environment to Cloudflare's network for vulnerabilities.

Deployment Process

As I continued reading `build_tool` to investigate the deployment process, I discovered that an executable file named `wrkr` was involved.

This program is written in Rust and is executed from `build_tool` in the following manner.

```
# Configure api proxy through the maestro
os.environ['CF_API_HOST'] = config['MAESTRO_HOST']
os.environ['CF_API_TOKEN'] = config['JWT']
os.environ['CF_ACCOUNT_ID'] = config['CF_ACCOUNT_ID']
[...]

# WRKR (ASSET UPLOADER)
upload_args = {
  'account_tag': config['CF_ACCOUNT_ID'],
  'asset_namespace': config['ASSET_NAMESPACE'],
  'asset_dir': asset_dir,
  'asset_manifest_namespace': config['MANIFEST_NAMESPACE'],
  'asset_manifest_key': config['MANIFEST_KEY'],
}

cmd = ['./wrkr']

[...]
lines = filter_logs(util.run_cmd(cmd, cwd=constants.WRKR_DIR))
```

As the code above shows, `wrkr` can switch its connection destination by setting the environment variable `CF_API_HOST`. I tried to inspect the communications by specifying a reverse proxy I had set up myself instead of the original destination, `api.pages.cloudflare.com`.

As a result, I learned that deployment proceeds as follows.

[image: Diagram showing the deployment flow]

Internal API

Using the reverse proxy above to investigate the API endpoints on api.pages.cloudflare.com, I found that the following endpoints were being used:

- `/client/v4/accounts/d6fa5e8917ff81a61c1f92fc98b9f85d/storage/kv/namespaces/db62b722715546c9af0cedbd574c9a47/bulk`
- `/client/v4/accounts/d6fa5e8917ff81a61c1f92fc98b9f85d/storage/kv/namespaces/db62b722715546c9af0cedbd574c9a47/keys`
- `/client/v4/accounts/d6fa5e8917ff81a61c1f92fc98b9f85d/storage/kv/namespaces/332a39fcd8a845d7909d2d5d753604d8/values/builds/5486590/logs`

As these paths show, this API forwards requests to api.cloudflare.com and returns the response. I therefore tried using the JWT attached to requests to this API to send a request to `api.cloudflare.com`, but it was treated as an invalid token and I could not receive a response. I also tried requesting endpoints other than those used here, but those attempts also failed. It appeared that this API proxy restricted which API endpoints could be used.

While conducting this investigation, I noticed that all three of us doing the research had been assigned the same account ID (`d6fa5e8917ff81a61c1f92fc98b9f85d`).

[image: Realizing on Discord that the account IDs were identical]

Path Traversal

On closer inspection, as mentioned above, the account being used was shared by all users, but one of the two KV namespaces in use changed with every deployment. I therefore tried to access another user's namespace, but this failed because identification appeared to be performed using the JWT. The namespace shared by all deployments also used key-based access control with a deployment ID unique to each deployment, so I could not access other users' data there either.

Then, at Sean's suggestion, we decided to try bypassing the API restrictions using path traversal.

[image: Image of Sean proposing path traversal on Discord]

We tried several patterns, but could not perform path traversal, and the general feeling was that path traversal did not seem possible. With no further ideas but not wanting to give up, I was experimenting with the API when a list of other users' namespaces suddenly appeared.

[image: Reporting the successful path traversal on Discord]

It seems that requests to the namespace shared by all deployments underwent strict path checks, but requests to namespaces created for each deployment had looser path checks. By appending a string such as `..%2F..%2F..%2F` to the end of the path, it was possible to send requests to any API on api.cloudflare.com that was not intended to be accessible.

Impact

After testing various APIs to investigate the impact, it appeared that the permissions of the API key used by this API proxy were limited to Cloudflare Workers KV-related operations. Even so, it was possible to retrieve all Pages static files deployed to date, the Cloudflare Workers code used on Pages, build logs, and other data. It should also have been possible to tamper with deployed content by rewriting other people's files immediately after they were uploaded.

Summary

This article explained the sequence of events involved in collaborating with several researchers to look for vulnerabilities in Cloudflare Pages. As mentioned at the beginning, several vulnerabilities had already been found and fixed in Cloudflare Pages. Nevertheless, we were still able to find a high-severity vulnerability, demonstrating that vulnerabilities may exist even in services that have already been tested.

Please send questions or comments about this article to Twitter (@ryotkak).

Acknowledgments

I would once again like to thank James Hebden and Sean Yeoh for helping with this research. Thank you.

Timeline

| Date (Japan Standard Time) | Event | | | 2022/05/14 | Arbitrary file read discovered | | | 2022/05/14 | Request for collaboration sent | | | 2022/05/15 | Privilege escalation discovered | | | 2022/05/15 | Path traversal in the Pages internal API discovered | | | 2022/05/15 | These three vulnerabilities reported to Cloudflare | | | 2022/05/17 | Path traversal in the internal API fixed | | | 2022/06/07 | Arbitrary file read in the build environment fixed | | | 2022/06/08 | Privilege escalation in the build environment fixed | | | 2023/12/22 | Permission to disclose granted | | | 2023/12/23 | This article published | |

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Binaries and code for processes running in the build environment, etc.

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Because the investigation began on a Saturday, and we wanted to finish it during the holiday.

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https://github.com/npm/npm-package-arg/blob/2dd33f52a772c091f26169c97cefaa399a7233cc/lib/npa.js#L77-L85