NEURAL INFORMATION PROCESSING SYSTEMS

AFBench: A Large-scale Benchmark for Airfoil Design

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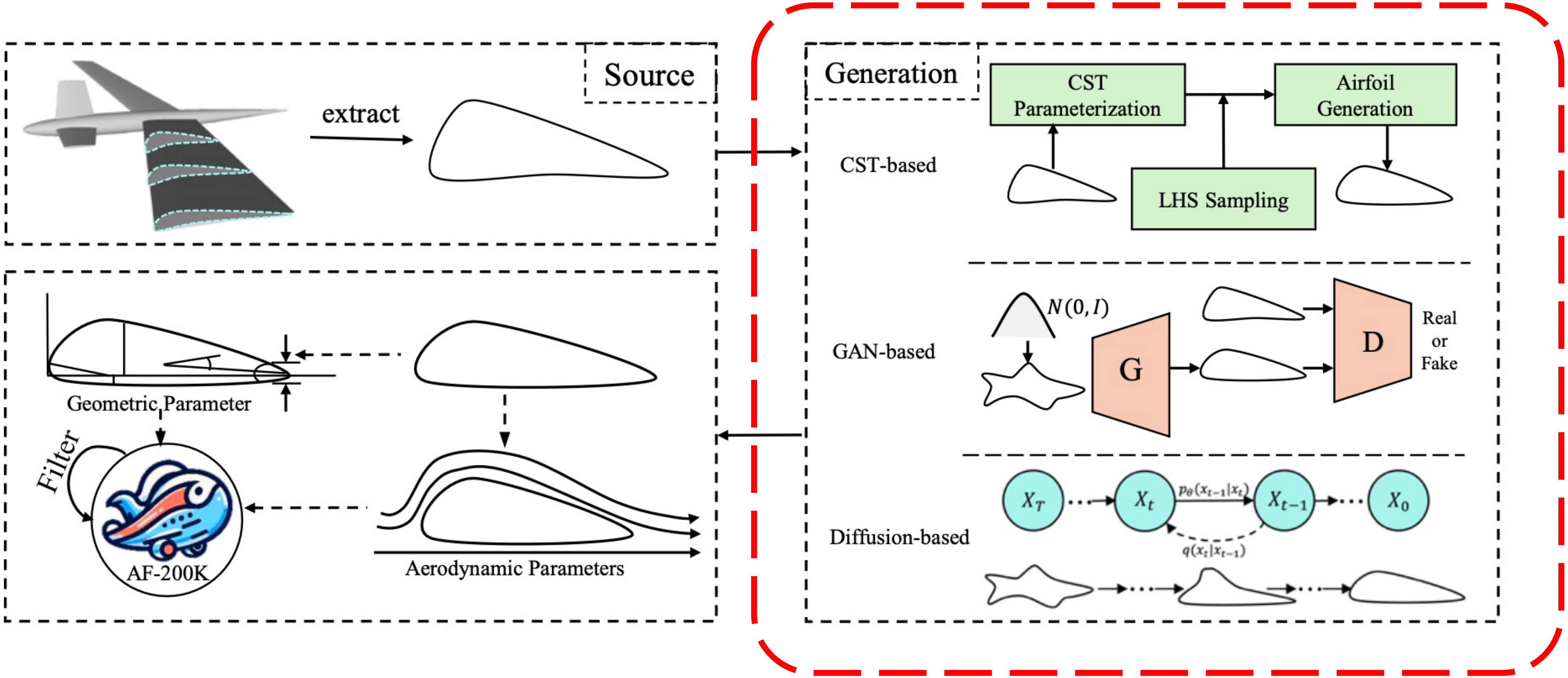
Motivation

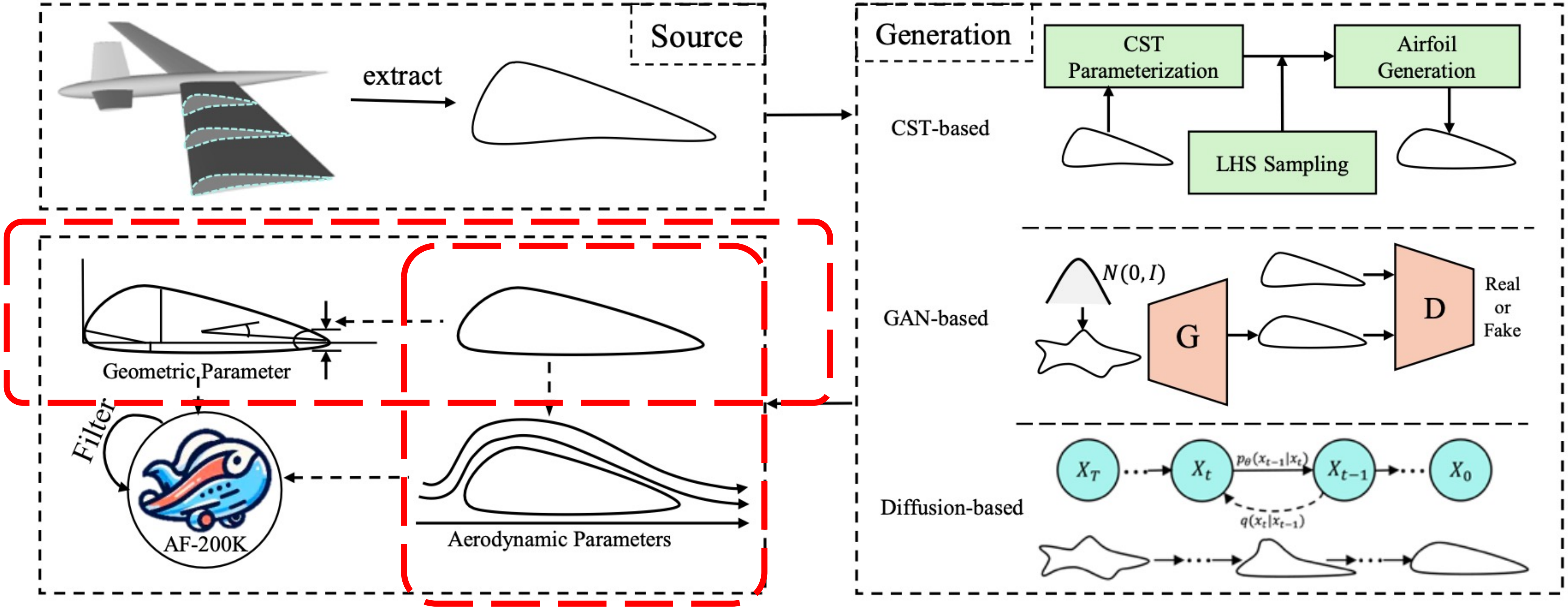
- The existing airfoil datasets are relatively **small-scale**.
- The current datasets typically provide only **a single condition**.
- The current methods do not support progressive **editing** existing designs.
- Lack of a **comprehensive and clear codebase** to compare and analyze different approaches.

Automatic Data Engine



1. Generation stage:
   - CST-assisted Generation
   - Unconditional Airfoil Generation

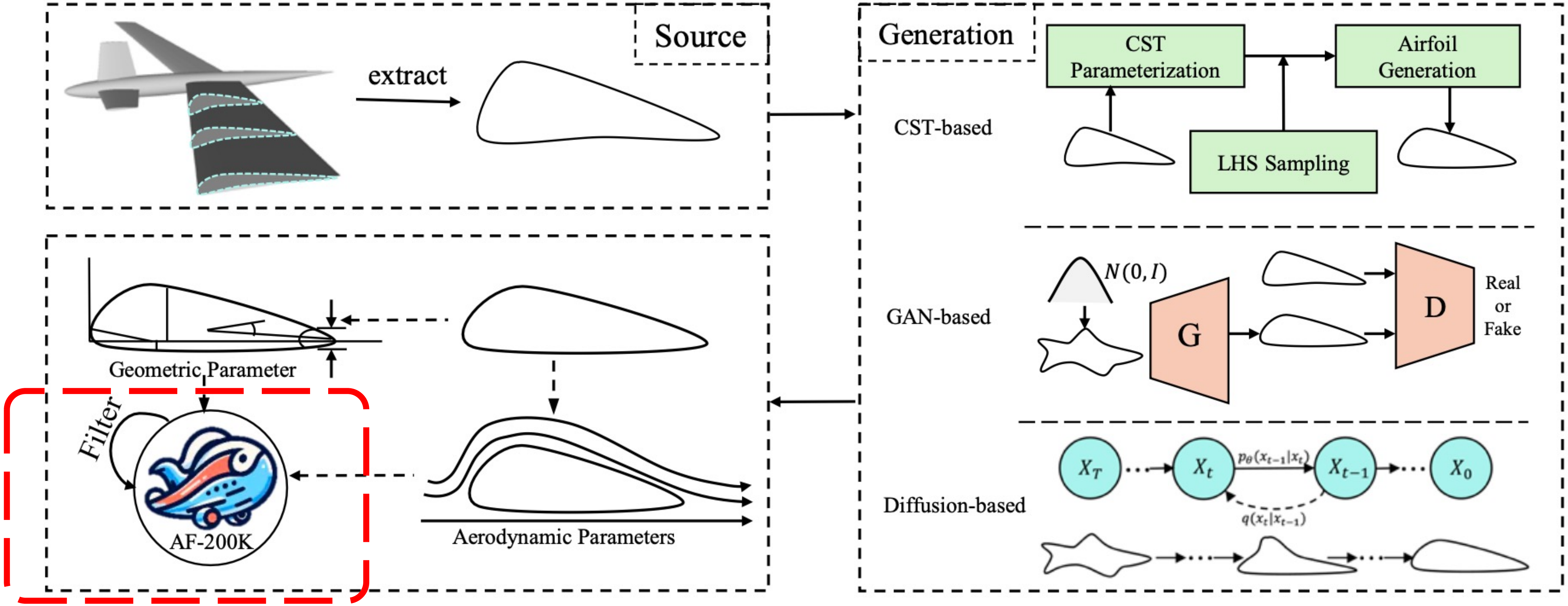
Automatic Data Engine



2. Annotation stage:

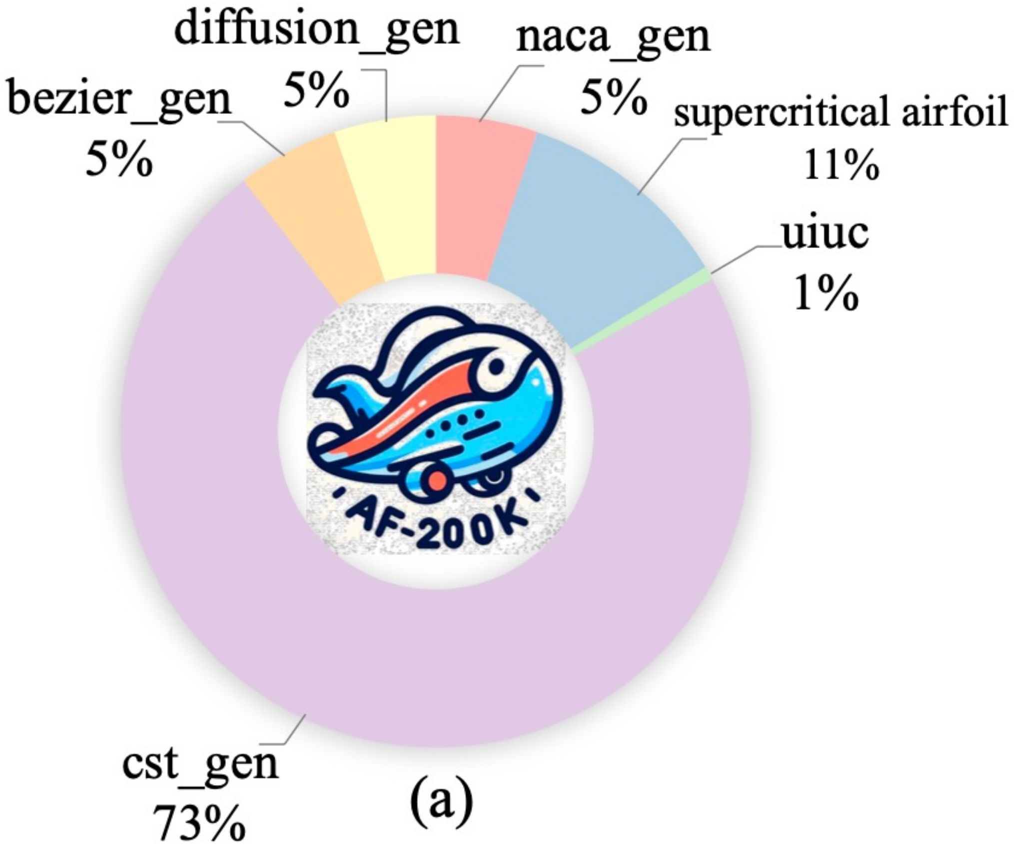
- Aerodynamic
- Geometric

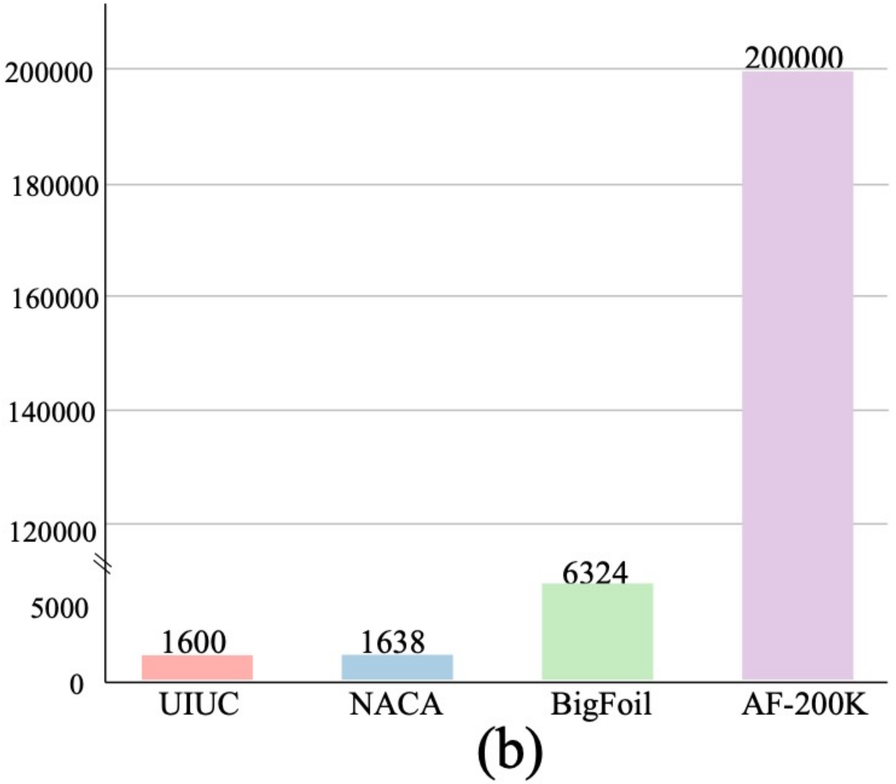
Automatic Data Engine



3. Filtering stage

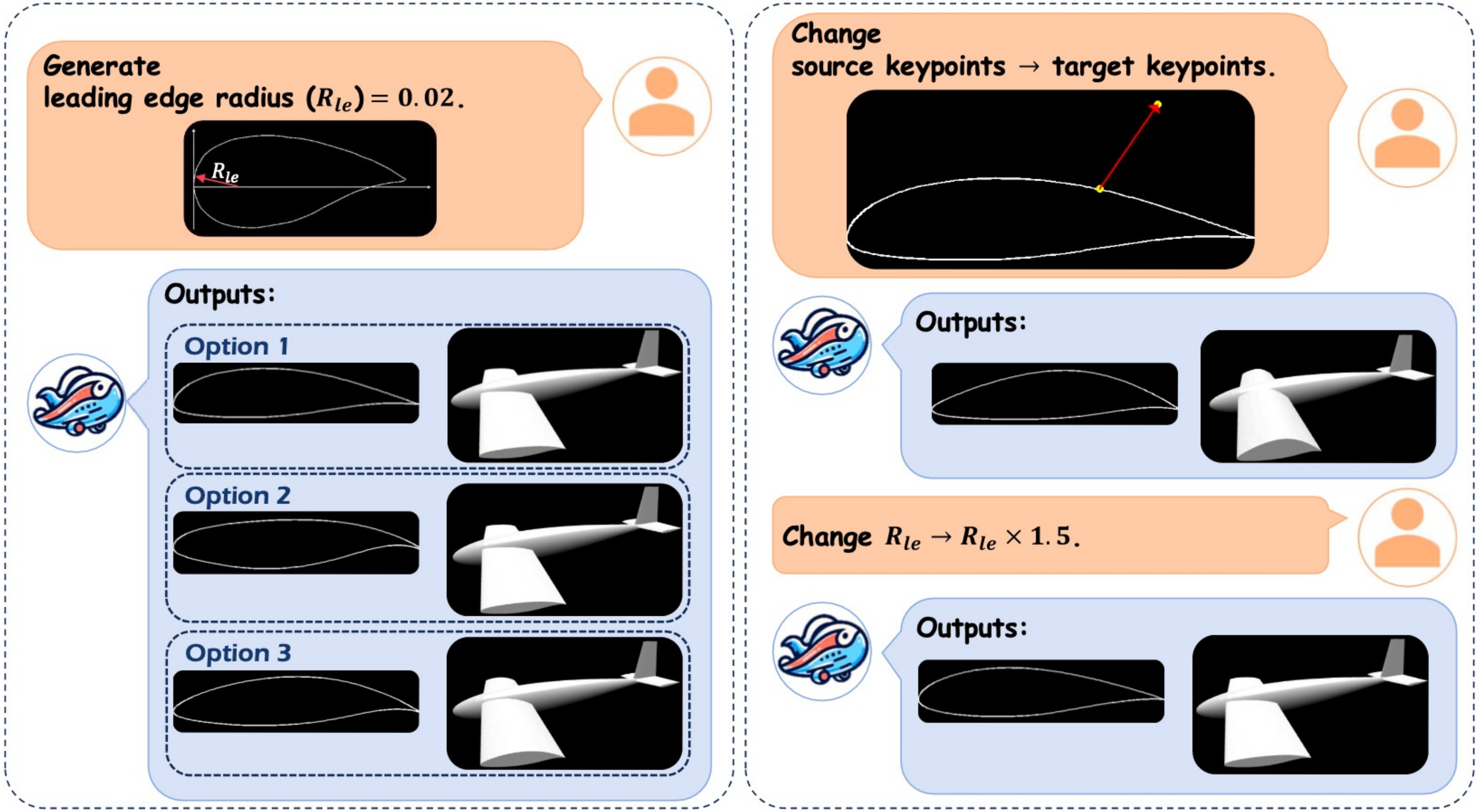
Dataset & Benchmark





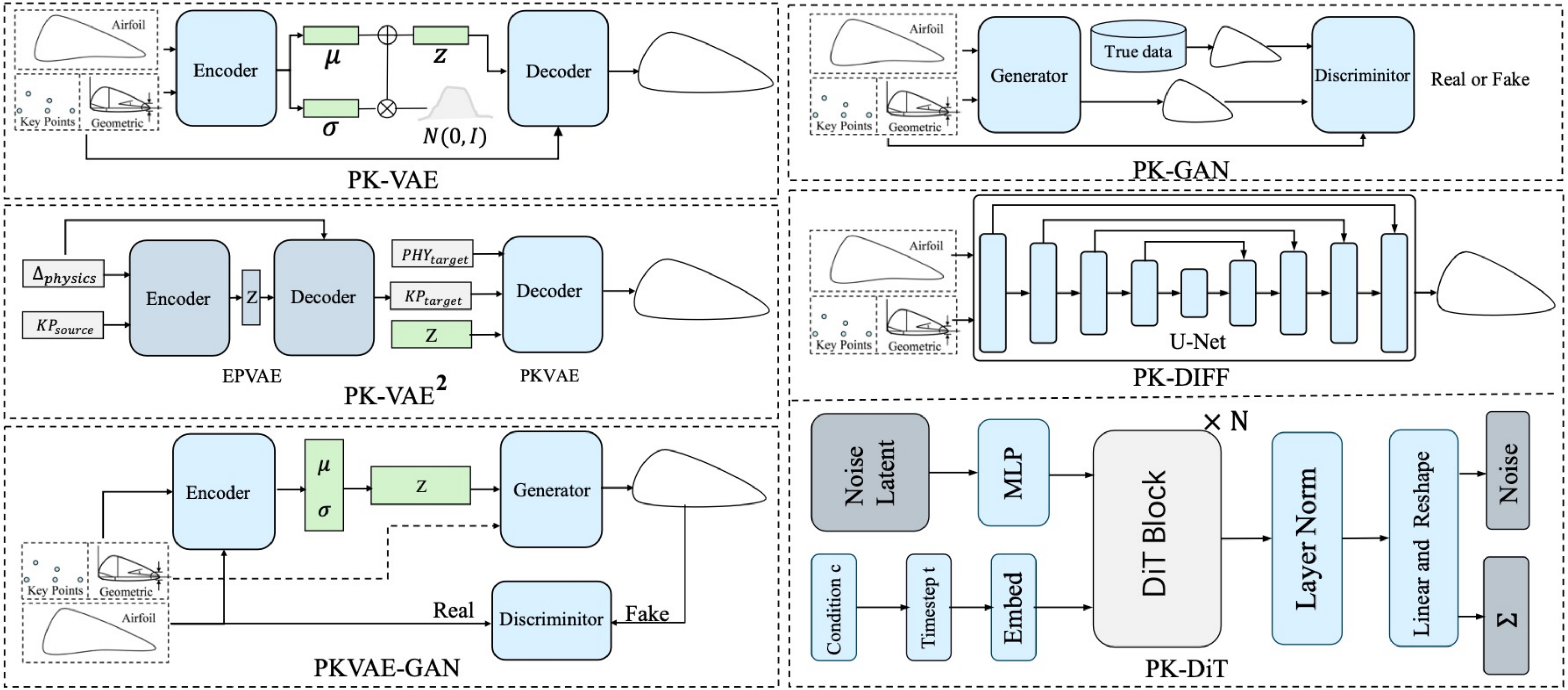
Dataset presentation

Dataset & Benchmark



Two Airfoil Inverse Design Tasks

Dataset & Benchmark



The baseline methods for benchmarking the dataset

Dataset & Benchmark

Comprehensive metrics:

- Label error: $\sigma_i = |\hat{p_i} - p_i|, i = 1, 2, ..., 11$
- Diversity: $\mathcal{D} = \frac{1}{n}\sum_{i=1}^{n} \log det(\mathcal{L}_{S_i}),$
- Smoothness: $\mathcal{M} = \sum_{i=1}^{N} \text{Distance}_{Pn \perp |P_{n-1}P_{n+1}|},$
- Success rate: $\mathcal{R} = \frac{1}{N}\sum_{i=1}^{N} \mathbb{I}(\frac{\sum_{j=1}^{M} C_j}{M} > 60\%), j = 1, ..., M,$

Analysis

Method	Dataset	Label error↓ ×0.01												$\mathcal{D}\uparrow$	$\mathcal{M}\downarrow$ ×0.01
		σ_1	σ_2	σ_3	σ_4	σ_5	σ_6	σ_7	σ_8	σ_9	σ_{10}	σ_{11}	$\bar{\sigma}$		
CVAE [16]	AF-200K	7.29	5.25	3.52	1590	9.9	9.55	2900	1.91	1.53	4.6	10.4	413.1	-155.4	7.09
CGAN [15]	AF-200K	10.7	8.50	5.44	2320	14.3	13.7	5960	2.53	2.23	5.3	12.9	759.6	-120.5	7.31
PK-VAE	AF-200K	6.30	4.79	3.13	862	6.6	6.41	1710	1.35	0.93	3.3	7.8	237.5	-150.1	5.93
PK-GAN	AF-200K	8.18	6.30	4.70	2103	12.0	11.7	3247	2.25	1.96	5.0	12.7	492.3	-112.3	3.98
PKVAE-GAN	AF-200K	5.68	3.17	3.10	565	4.6	4.35	1200	0.91	0.51	2.8	6.3	163.3	-129.6	2.89
PK-DIFF	AF-200K	4.61	3.46	2.15	277	2.2	1.93	1030	0.70	0.11	2.4	3.1	120.6	-101.3	1.52
PK-DIT	UIUC	6.38	5.14	3.36	1183	8.7	8.49	2570	1.69	1.19	3.6	9.8	345.6	-141.7	6.03
PK-DIT	Super	5.20	3.50	2.40	301	2.9	3.32	1050	0.83	0.26	2.7	3.3	125.0	-123.4	1.97
PK-DIT	AF-200K	**1.12**	**3.23**	**1.54**	**105**	**1.3**	**1.15**	**979**	**0.05**	**0.05**	**2.3**	**2.4**	**99.7**	**-93.2**	**1.04**

Performance across different datasets

Analysis

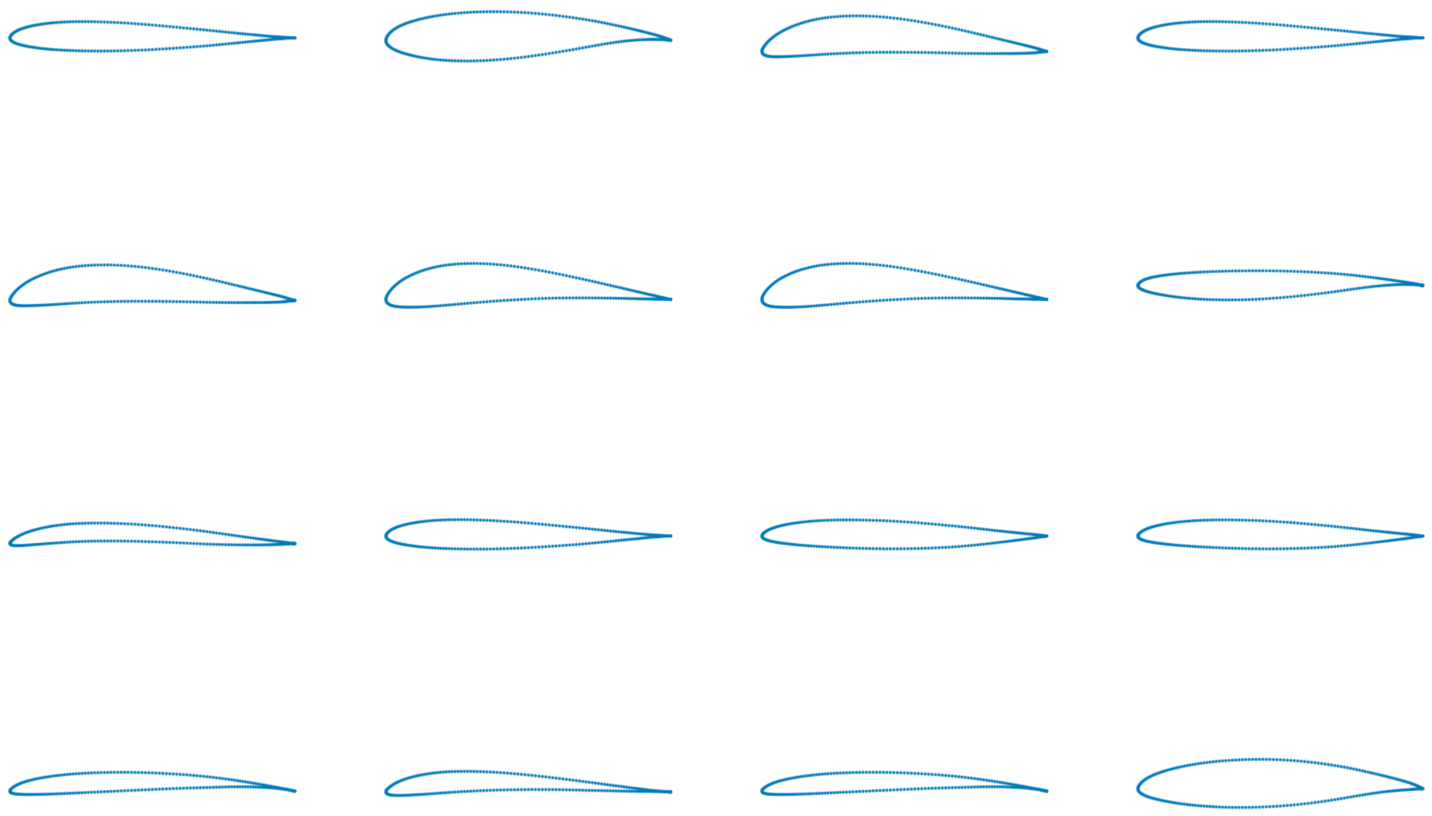
Method	Task	Label error↓ ×0.01												$\mathcal{D}\uparrow$	$\mathcal{M}\downarrow$ ×0.01
		σ_1	σ_2	σ_3	σ_4	σ_5	σ_6	σ_7	σ_8	σ_9	σ_{10}	σ_{11}	$\bar{\sigma}$		
PK-VAE	EK	9.3	8.33	5.27	2082	12.9	11.1	4620	2.51	2.04	5.1	11.8	615.5	-143.4	7.21
PK-VAE	EP	8.9	6.38	4.94	1780	10.9	9.4	4570	2.05	1.98	4.9	10.3	582.6	-150.8	7.19
PK-VAE^2	EK	7.1	5.71	4.05	1430	8.0	8.1	3780	1.91	1.52	3.6	8.7	478.1	**-133.4**	**6.20**
PK-VAE^2	EP	**6.5**	**5.22**	**3.57**	**1010**	**7.8**	**7.3**	**2010**	**1.52**	**1.03**	**3.4**	**7.9**	**278.5**	-135.6	6.36

Performance across different design tasks

Method	Label Error (×0.01)↓												$\mathcal{D}\uparrow$	$\mathcal{M}\downarrow$ ×0.01
	σ_1	σ_2	σ_3	σ_4	σ_5	σ_6	σ_7	σ_8	σ_9	σ_{10}	σ_{11}	$\bar{\sigma}$		
NACA-GEN	6.26	5.10	3.29	961	7.69	7.46	2130	1.08	1.038	3.4	8.0	284.9	-136.4	5.09
CST-GEN	5.82	4.09	2.80	572	4.61	4.36	1390	0.94	0.542	3.1	5.9	181.3	**-101.5**	2.31
BézierGAN-GEN	5.96	4.96	3.07	839	5.64	6.38	1900	0.98	0.817	3.1	7.4	252.5	-125.3	**1.21**
Diffusion-GEN	**5.44**	**3.83**	**2.58**	**353**	**3.09**	**3.33**	**1180**	**0.89**	**0.293**	**2.9**	**4.2**	**141.8**	-111.9	2.05

Performance across different generated data

Visualization

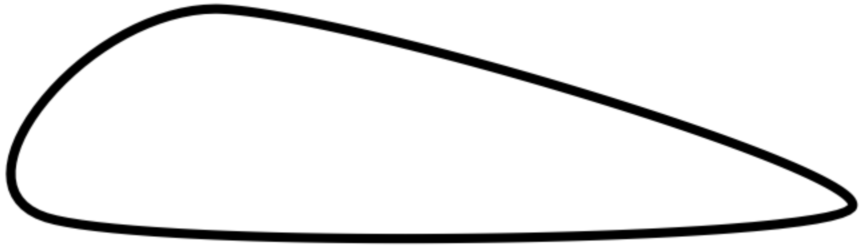


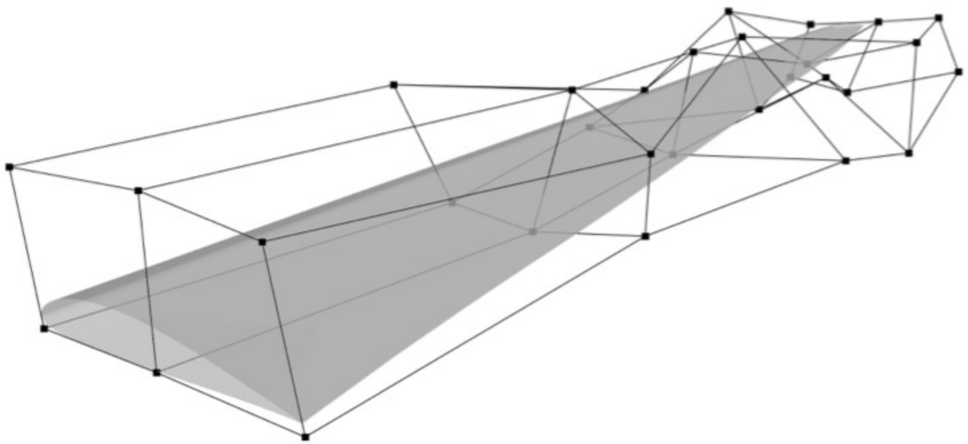
Diverse airfoils generated by PK-DIT

- A **large-scale and diverse** airfoil dataset.
- Improving the **capabilities** of data-driven models.
- Providing a **more comprehensive** benchmark.

Limitation & Future works

- Dealing with multiple conditions
- Optimization techniques integration
- Dimension extension





2D airfoil inverse design → 3D airfoil inverse design

Deep Generative Model for Efficient 3D Airfoil Parameterization and Generation
Wei Chen and Arun Ramamurthy
Arxiv, 2021

Github

Zhihu

Arxiv

Thank you!