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Supplement of

4D Aviation Emission Inventory Data of China estimated with QAR data in 2023 (4D-AEID-2023)

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Supplementary Table

Table S1. Summary of QAR Flight Screening and Data Retention

Data Processing Stage	Proportion of Raw Records (%)
Raw QAR records	100.0%
Flights beyond the study scope	6.2%
Domestic flight candidate records	93.8%
Invalid records	0.6%
Final valid domestic flights	93.2%

Table S2. 1-s Observation-Level Data Reconstruction Proportions

Variable	Original valid rate	After 30-s interpolation	After historical-flight matching
MACH	99.93%	100.00%	—
ALT_STD	87.28%	93.67%	100.00%
SAT	91.77%	98.75%	100.00%
FF1	99.36%	100.00%	—
FF2	99.43%	100.00%	—
GPS_LONG_CA	92.67%	98.27%	100.00%
GPS_LAT_CA	92.46%	98.31%	100.00%

Table S3. Point-Level Mask-Based Validation of Data Reconstruction and Its Impact on Total Emissions

Variable	Masking rate	Reconstructi--on method	R^2	RMSE	Bias	NOx deviation (%)	CO deviation (%)	HC deviation (%)	PM deviation (%)
MACH	0.07%	30-s interpolation	0.9998	0.008	+0.0001	−0.0001	+0.0000	+0.0001	+0.0001
ALT_STD	6.39%	30-s interpolation	0.9988	0.66	−0.02	−0.001	+0.000	+0.005	+0.004
SAT	6.98%	30-s interpolation	0.9992	0.62	+0.01	−0.001	+0.000	+0.004	+0.003
FF1	0.64%	30-s interpolation	0.9980	1.18	−0.04	−0.003	+0.001	+0.004	+0.003
FF2	0.57%	30-s interpolation	0.9978	1.26	−0.05	−0.003	+0.001	+0.005	+0.004
ALT_STD	6.33%	Historical-flig-ht matching	0.9968	2.01	+0.13	+0.007	−0.002	+0.006	+0.005
SAT	1.25%	Historical-flig-ht matching	0.9948	1.96	+0.11	+0.002	−0.002	+0.005	+0.004

Table S4. Flight phases and their meanings

Parameter Value	Flight Phase	Meaning
1	ENG. STOP	Engine Shutdown
2	TAXI OUT	Taxi Out
3	TAKE OFF	Takeoff
4	2 SEGMENT	Second Segment (Acceleration)
6	INIT. CLIMB	Initial Climb
7	CLIMB	Climb
8	CRUISE	Cruise
9	DESCENT	Descent
10	APPROACH	Approach
11	FINAL	Final
12	LANDING	Landing
14	TAXI IN	Taxi In

Table S5. Hierarchical aircraft-engine matching rules and corresponding flight coverage rates

Matching level	Matching method	Proportion
1	Exact	59.9904%
2	Normalized_Exact	22.0960%
3	Series_Fallback	0.0264%
4	Contains	9.0603%
5	Fuzzy	7.7783%
6	Core_Number_Fallback	0.0158%
7	Information_Inference	1.0328%
	Total	100.0000%

Notes:

Detailed criteria for each matching level are as follows:

(1) Direct exact matching. The original engine designation was directly compared with the EEDB engine identifier for an exact string match.

(2) Standardized exact matching. If no direct match was found, both engine designations were standardized by harmonizing letter case, removing spaces, and normalizing symbols such as underscores and hyphens, followed by another exact comparison.

(3) Engine-series matching. If the complete engine subtype remained unresolved, the available engine series was used to identify a corresponding generic engine designation within the same engine family.

(4) Containment matching. The matching was further relaxed by checking whether the core engine designation appeared as a complete substring within the EEDB designation.

(5) Fuzzy matching. For records that remained unresolved, fuzzy matching based on Levenshtein similarity was applied, with a similarity threshold of 0.80.

(6) Numerical-sequence matching. If fuzzy matching also failed, the characteristic numerical sequence contained in the engine designation was extracted and used to identify the corresponding EEDB candidate.

(7) Historical-information matching. When the engine description was missing or insufficient for direct EEDB matching, historical engine information was used sequentially, first from the same aircraft registration, then from the historically dominant engine associated with the same aircraft type, and finally from the representative engine assigned to that aircraft type.

Supplementary Figures

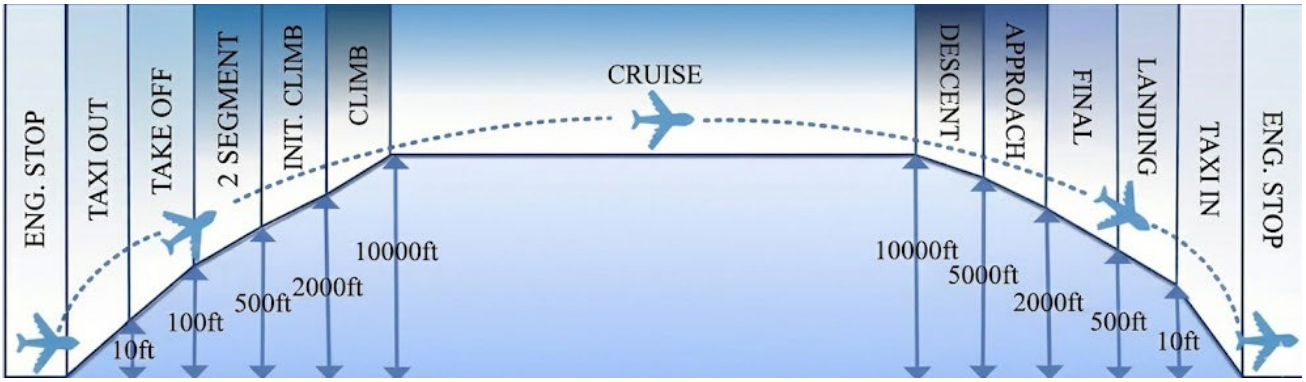
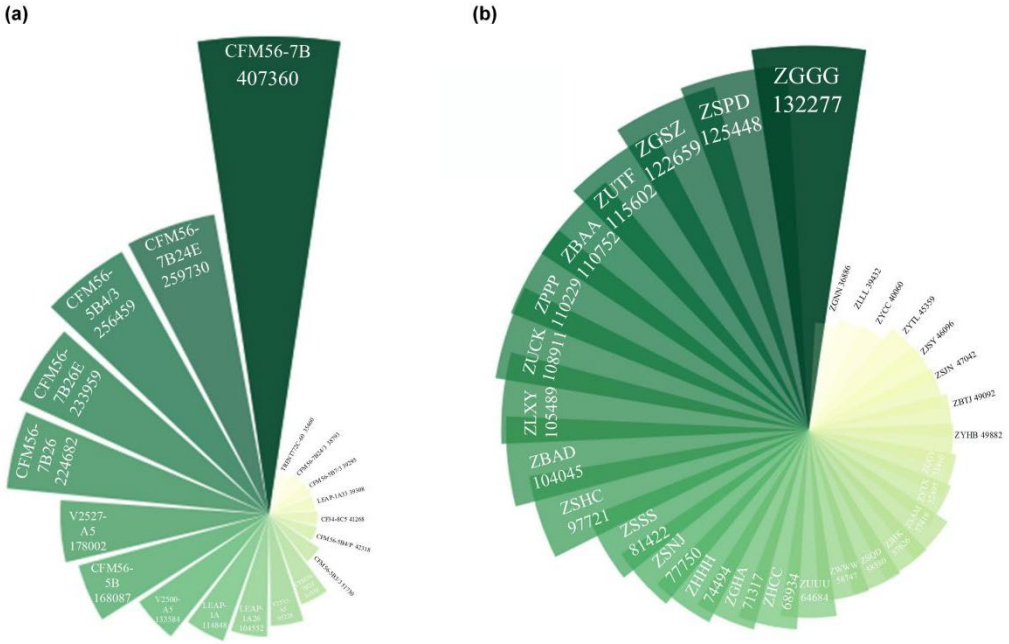


Figure S1. Schematic representation of flight phase segmentation.



70 **Figure S2. Statistical distribution of major engine models and departure airports for China's civil aviation in 2023.**

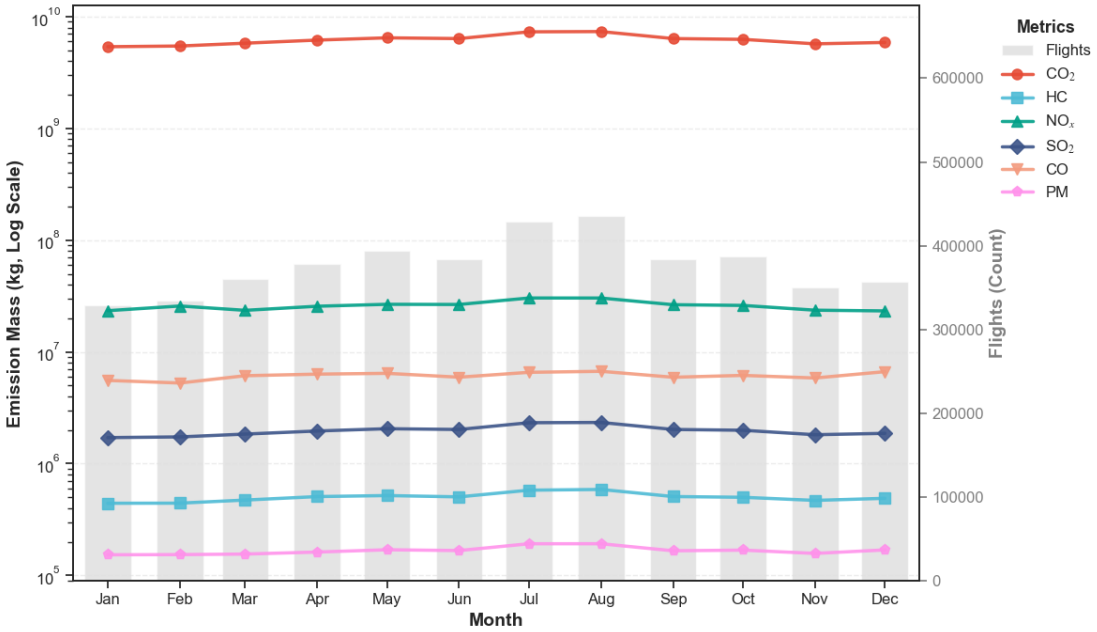


Figure S3. Monthly trends of flight traffic and total emission mass by pollutant type in 2023.