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emerald sky

CIRIUM'S FLIGHT EMISSION APPROACH AND DOCUMENTATION
FOR 2025



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Change history

Author	Date	Version	Comment
Tom Keogh	11/01/2024	1.0	Initial document describing the first version of the Cirium emissions methodology used in 2022
Tom Keogh	11/01/2024	1.1	Methodology updates for 2023; improved aircraft deterioration schedule and dynamic load factors model.
Jim Hetzel	09/02/2024	1.2	Published
Jim Hetzel	12/07/2024	1.6	Corrected misprint of deterioration schedule value for wide-body – Age < 1 year. Added table of contents.
Jim Hetzel	05/11/2024	1.7	Modified Fuel Burn Model section for clarity.
Rachel Humphries	16/09/2025	1.8	Methodology updates for Load Factor and Zero Fuel Weight sections.



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EmeraldSky - Flight Emissions Methodology

Cirium has developed EmeraldSky an advanced combination of data, analytics, and methodology to provide a standard and accurate picture of CO₂ emissions and fuel burn calculations per flight and aircraft seat. Cirium's EmeraldSky calculates the most accurate, historic, and predicted flight emissions data in the marketplace.

Why create our own?

Cirium has fused numerous data elements including but not limited to, aircraft and engine specifications, airline schedules, and actual flight operations to create a holistic view of the actual emissions footprint. This enables Cirium clients to view the emissions by operator, aircraft type or geographical region and on a historical, or predictive basis, solving a variety of use cases.

Our mission is to establish the standard for accurate fuel burn and carbon emissions data to empower the aviation industry to deliver on its sustainability targets. For the industry to achieve their goals of cutting CO₂ emissions in half by 2050 compared with 2005, a clear, accurate measurement methodology is needed.

We calculate our estimates for each flight using many 'real world' data points, including actual airframe and engine master series, winglet type (where fitted), number of seats on board, aircraft age, tracked taxi time, and actual air minutes (NOT simply great-circle distance between airports).

We also employ methodologies to adjust for each aircraft's typical operating weight, passengers and baggage, cargo payload and degradation in engine efficiency over time.

Furthermore, our solution is also a truly 'neutral' offering from a trusted industry data partner.

Our methodology – High Level Summary

We take our tracked utilisation ¹ data and feed it through proprietary aircraft fuel burn models, to generate estimates of block (gate-to-gate) fuel consumed for individual flights. We convert these figures into CO₂ emitted values.

We consider multiple factors to arrive at accurate historical and future forecasted emissions calculations, including:

- Aircraft Type (including age, engines fitted, fit of winglets/sharklets)
- Time & Distance
- Seating Configuration
- Passenger Payload
- Freight Payload
- Schedule Forecasting

¹ <https://www.cirium.com/solutions/tracked-aircraft-utilization/>

EmeraldSky – key differentiators

Differentiation	Why this matters
Aircraft – Derived from Cirium’s fleets database	
Cirium’s fuel burn calculation considers the aircraft/engine master series, operating empty weight, whether winglets have been fitted and the aircraft age.	Different aircraft types have different fuel burn profiles. The fuel efficiency of an aircraft is improved by the presence of winglets and deteriorates with the age of the aircraft.
Flights – Derived from Cirium’s Tracked Utilisation data	
Cirium calculates estimated fuel burn based on actual tracked flight time and taxi times.	This distinguishes between flights of a similar great circle distance, by considering different track routings, headwinds, holding patterns and fuel burn on the ground. For example, this allows for accurate calculations for flights routing around Russian airspace at present. The fuel burn for the aircraft is then multiplied by a constant to get the amount of CO ₂ emitted.
Seating Configuration – Derived from Cirium’s Fleets Database	
Cirium’s approach accounts for each individual aircraft’s seating configuration, including the actual pitch and width.	Seating data allows for more accurate assessment of passenger payload, and the configuration data determines how much space and therefore what proportion of the CO ₂ emissions each seating class will be responsible for.
Passenger Payload – Derived from airline traffic data	
Cirium has created a carrier specific, monthly load factor model based on years of reported airline traffic data. which is applied to each historical and scheduled flight.	Fuel burn varies according to the payload carried, and flights with a lower proportion of occupied seats will be less efficient on a per-passenger basis than those that are fuller.
Freight Payload – Derived from Cirium’s Ascend Consultancy	
Cirium uses a cargo payload assumption for each widebody aircraft type, both for	Cargo payload needs to be considered in estimating the overall aircraft weight and fuel



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Differentiation	Why this matters
passenger and all-cargo aircraft. However, we are working towards making the payload data more granular by carrier and market.	burn. A share of the CO ₂ emitted by widebody flights should be allocated to the cargo payload, before any split between passenger classes is evaluated

Emissions Data Coverage

We can provide estimates for any flight against which we are able to match an aircraft tail number. Our global match rate for tracked flights is approximately 99.8% for widebodies, 98.6% for narrowbodies and 94.5% for regional types. Coverage varies by region and is higher for areas with more extensive ADS-B coverage and lower for operations into remote airports using smaller aircraft.

Historical vs Forecasted Emissions

Cirium's emissions datasets covers flights both historical and in the future. Our historical emissions data based on Tracked Utilization dates starts in 2017, providing 5+ years of global aircraft emissions data.

Cirium's forecasted emissions dataset predicts future emissions for all flights in a 1 year rolling window of global flight schedules. The global flight schedule emissions forecast is updated daily reflecting the latest operational changes by airlines globally.

Forecasting emissions based on historical datasets

With Cirium's industry leading EmeraldSky methodology generating 5 years of historical emissions using the contributing factors above, Cirium can infer emissions on scheduled flights using this detailed and rich dataset.

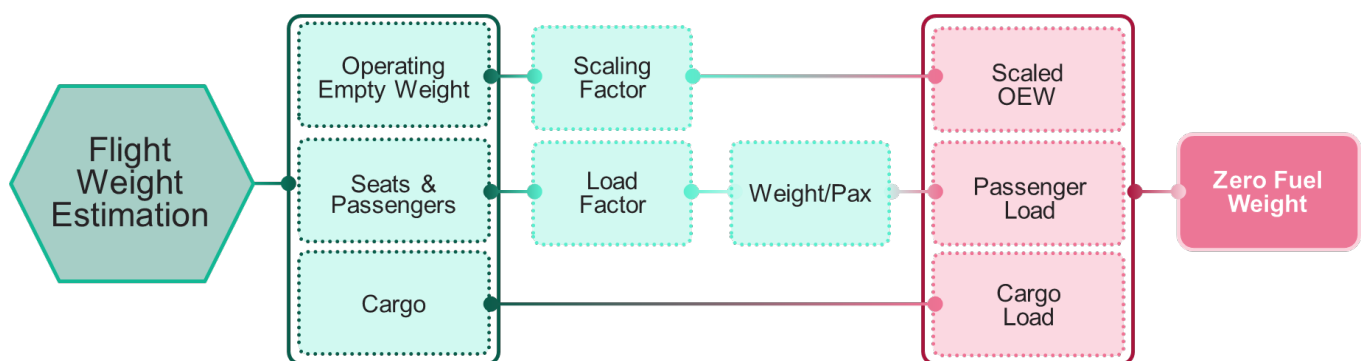
We use our historical emissions datasets as training data for our machine learning models to predict emissions for a given flight in the global flight schedule. We constantly monitor and enhance the models based on our accuracy success at predicting the flight's scheduled emissions with its historical emissions.

With Cirium's existing global coverage of flight schedules, we are now able to append each future scheduled flight with fuel burn and CO₂ emissions datapoints.

Methodology

Our methodology comprises of the following stages:

Flight Weight Estimation



Load Factor

Cirium has created a passenger load factor model based on our traffic datasets. This provides years of collated airline traffic data. We have applied multiple techniques of smoothing and aggregating to create a carrier-specific, monthly load factor value which can be applied to each historical and scheduled flight.

Where direct carrier-specific load factor data is unavailable, we use parent group information—such as airline alliances or parent companies—to impute missing values. This approach leverages broader operational trends to improve coverage and reliability.

In cases where neither carrier-specific nor parent group data is available, we apply an 84% load factor to those flights. This is based on average load pre-Covid in 2019. Load factor is used to estimate the number of passengers and associated weight.

The methodology will continue to evolve as improved data sources and logic become available.

Zero Fuel Weight

The zero fuel weight (ZFW) for each flight is calculated as the sum of the scaled operating empty weight, cargo tare weight, passenger load, and cargo revenue payload. This update ensures that cargo tare weight—defined as the mass of containers, pallets, and packaging—is accounted for



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separately and added to the operating empty weight, rather than being included in the revenue payload.

Equation:

Zero Fuel Weight (ZFW) = (Operating Empty Weight (kg) × Scaling Factor) + Cargo Tare Weight (kg) + Passenger Load (kg) + Cargo Revenue Payload (kg)

Where:

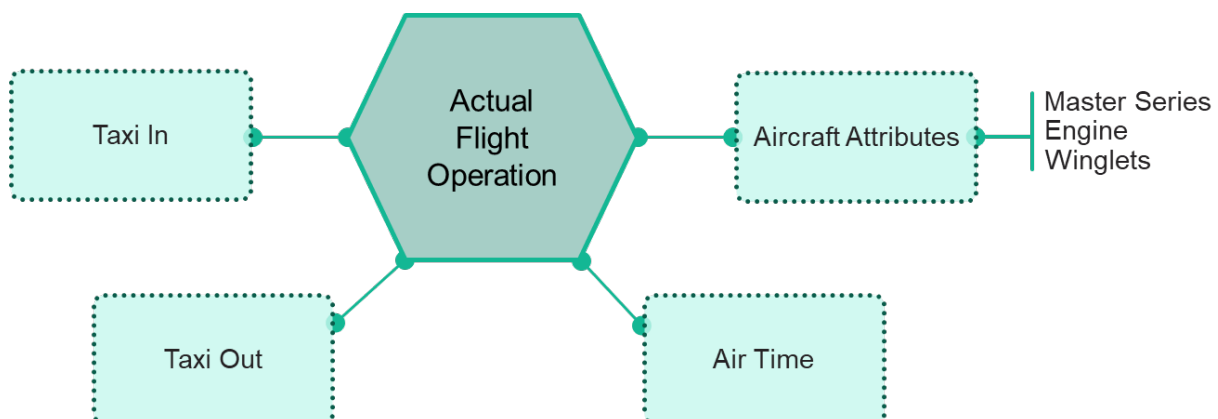
- **Operating Empty Weight (OEW):** The aircraft's empty weight, excluding cargo tare weight, multiplied by a scaling factor (1.03 or 1.05) as recommended by Cirium Consultancy.
- **Cargo Tare Weight:** The mass of containers, pallets, and packaging, determined by aircraft model lookup and added separately to OEW.
- **Passenger Load:** Number of seats × load factor × standard passenger weight (100 kg).
- **Cargo Revenue Payload:** The mass of revenue-generating cargo, excluding tare weight.

All weights are capped at the aircraft's maximum zero fuel weight, ensuring the sum does not exceed operational limits.

Note:

This approach improves the accuracy of emissions allocation between passengers and cargo and supports more precise calculation of Revenue Tonne Kilometres (RTK) for sustainability reporting.

Flight Operation



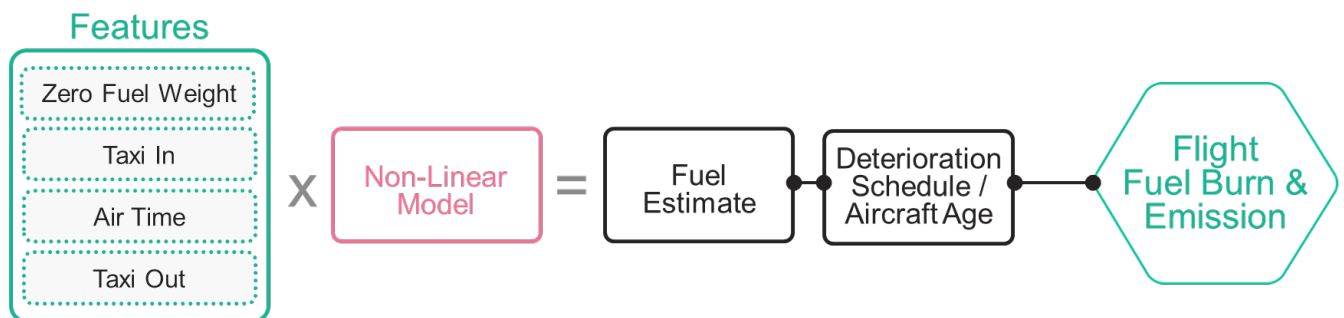


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Cirium utilises our Tracked Utilization dataset to model emissions based on the actual performance of the aircraft operating flight. By accurately modelling the fuel burn of each individual flight, daily operational variances are recorded in our emissions datasets. For each flight operation, we use the following properties to model fuel burn:

- Taxi in time (minutes)
- Taxi out time (minutes)
- Air time (minutes)
- Attributes of aircraft operating the flight

Fuel Burn Estimation



Fuel Burn Model

Cirium uses propriety fuel burn models supplied by an independent a 3rd party to provide a fuel burn profile specific to each aircraft's combination of:

- Aircraft Master Series
- Engine Master Series
- Winglets

The rate an aircraft burns fuel is nonlinear. This is because the weight of the aircraft is highest at the beginning of the flight's operation. As it burns fuel it becomes lighter and thus more efficient as it burns of the weight of the fuel.

Fuel burn profile data is used to fit a non-linear model for each aircraft combination. Generally, the fit of these models features r-squared values close to .99. Note - coefficients for taxi out and taxi in minutes are not learned from data, but rather contributed by Cirium Ascend consulting per model.



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The fuel burn models include the following features:

- Intercept
- Zero Fuel Mass (in kg)
- Trip Minutes
- Trip Minutes – Squared
- Interaction Term – Zero Fuel Mass (in kg) * Trip Minutes
- Taxi Out Minutes
- Taxi In Minutes

The fuel calculation occurs in two steps, the first of which is a linear combination of the matched model and data features. Data features are described in this section. For the fuel computation, we add:

- Intercept
- Coefficient Zero Fuel Mass kg x Zero Fuel Mass kg
- Coefficient Trip Minutes x Actual Air Time
- Coefficient Trip Minutes Squared x Actual Air Time ^ 2
- Coefficient Taxi Out Minutes x Taxi Out
- Coefficient Taxi In Minutes x Taxi In
- Coefficient Interaction Zero Fuel Mass kg x Trip Minutes = Zero Fuel Mass kg x Actual Air Time

Deterioration Schedule

Cirium adjust the fuel burn based on the age of the aircraft (i.e., deterioration) to reflect the impact of wear on older aircraft. In general, narrow body aircraft deteriorate more aggressively than wide body due to a higher frequency of landing/take-off cycles.

The following multipliers have been applied by Cirium Ascend Consultancy and validated with partner airlines:

Narrow Body

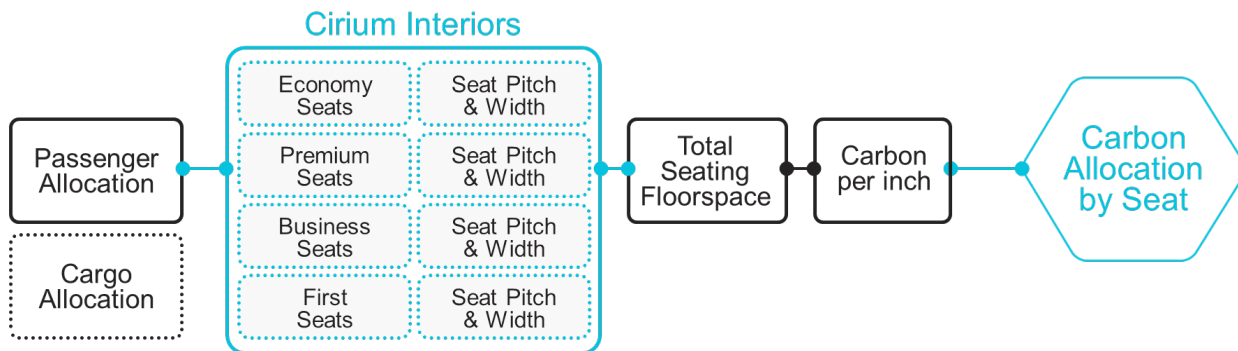
- Age < 1 Year = 1.0
- Age 1-2 Years = 1.02
- Age 2-3 Years = 1.04
- Age 3-10 Years = 1.05
- Age 10+ Years = 1.06

Wide Body

- Age < 1 Year = 1.005
- Age 1-2 Years = 1.01
- Age 2-3 Years = 1.015
- Age 3-10 Years = 1.018
- Age 10+ Years = 1.02

Fuel_estimate = Linear Model x deterioration multiplier

Carbon Allocation



The fuel burned is first converted to carbon by a constant multiplier of 3.16. The DEFRA model includes a radiating force multiplier of .9, but that multiplier is not applied to the Cirium estimate of carbon emission:

- $CO_2_estimate = Fuel\ estimate \times 3.16$

Allocation of Carbon to Seats

Cirium's cabin interiors approach to allocating carbon uses seat pitch, seat width, and number of seats from Cirium's Fleet's database to produce an allocation of the passenger portion of flight carbon to an individual booking.

A ratio of the passenger load vs cargo load is computed:

- $Passenger\ ratio = Passenger\ load / (Passenger\ load + Cargo\ load)$
- $Passenger\ CO_2\ estimate = Flight\ CO_2\ estimate \times Passenger\ ratio$

Carbon of Seat

Using number of seats, seat width, and pitch for each cabin in the aircraft we compute the total number of inches of seating area. Whilst this approach has the advantage of utilising carrier specific seat data, it does not include aisles, restrooms, premium cabin passenger facilities etc. This is an ongoing area of research and development at Cirium.

- $Seating\ Area\ Economy = Seats\ Economy \times Seat\ Pitch\ Economy \times Seat\ Width\ Economy$
- $Seating\ Area\ Premium = Seats\ Premium \times Seat\ Pitch\ Premium \times Seat\ Width\ Premium$



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- Seating Business = Seats Business x Seat Pitch Business x Seat Width Business
- Seating First = Seats First x Seat Pitch First x Seat Width First

Total Inches is computed by summing the total area of each cabin's seating area:

- Total Area = Seating Area Economy + Seating Area Premium + Seating Business + Seating First

Carbon per Inch is computed by dividing the CO₂ allocated to the passengers divided by the total area.

- CO₂ per Inch = Passenger CO₂ estimate / Total Area

Finally, Carbon per Seat is computed by multiplying a cabin's seat pitch and width by the CO₂ per inch:

- Carbon Economy Seat = Seat Pitch Economy x Seat Width Economy x CO₂ per Inch
- Carbon Premium Seat = Seat Pitch Premium x Seat Width Premium x CO₂ per Inch
- Carbon Business Seat = Seat Pitch Business x Seat Width Business x CO₂ per Inch
- Carbon First Seat = Seat Pitch First x Seat Width First x CO₂ per Inch

Seat Pitch and Width Fallback

To approach cases of missing seat data, we apply fallback methods and use more generalized averages produced from all flight level data from 2019-01-01 through 2021-11-01:

- Flight Level from historical data.
- Operating Airline + Aircraft: An average of all flight level data aggregated by operating airline and aircraft type subseries.
- Aircraft: An average of all flight level data aggregated by aircraft type subseries.
- Global: An average of all aircraft level aggregates.

Example – Allocation of Carbon to passenger booking economy seat:

- Total Flight Carbon 150,000kg
- Passenger / Cargo Ratio 3:1 (.75 Passenger - .25 Cargo)
- Seating by Cabin 120 Economy, 12 First
- Seat Pitch & Width Economy – 33 Inch Pitch & 18 Inch Width
- Seat Pitch & Width First – 39 Inch Pitch & 21 Inch Width
- Space Economy Seat = 594 Inches²
- Space First Seat = 819 Inches²
- Space Economy Cabin = 594 x 120 = 71,280
- Space First Cabin = 819 x 12 = 9,828



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- Total Aircraft Seating = $71,280 + 9,828 = 81,108$
- Carbon Per Inch = $150,000 \times .75$ (Passenger Ratio) / $81,108 = 1.387$
- Allocation to Economy Seat = $594 \times 1.387 = 823.878 \text{ CO}_2$

Calculating emissions using RELX Travel Data

Cirium provides RELX with highly accurate flight emissions data to feed into the Flights section of the RELX CO2 Hub – an internal analytics platform used to quantify RELX's Scope 3 emissions. The following section of this document describes the data processing stages between RELX and Cirium.

RELX Business Travel Data

RELX collects booked air travel data made through their travel provider BCD travel. The BCD travel data is supplied as traveller booked flight segments (as opposed to the individual flight legs) with arrival/departure datetimes and booked cabin class.

Cirium trips processing

Cirium matches RELX traveller flight segments to an actual flight leg in our historical emissions dataset. Cirium completes this complex matching process between bookings and historical flights leveraging our Tracked Utilization data product. This allows us to match the marketing airline for which the ticket was booked vs the operating airline which completed the corresponding flight leg². Our historical flight emissions datasets contain flight level fuel and CO2 emissions and seat level emission for all four cabin classes – Economy, Premium Economy, Business and First calculated via the methodology described in this document.

With the RELX flight segment matched to the Cirium historical flight leg, Cirium appends the flight legs to the corresponding flight segments and sends the combined dataset back to RELX for integration into the RELX CO2 tool and annual report.