



ICAO Carbon Emissions Calculator

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1 Introduction

This document presents a general methodology developed for estimating the amount of carbon emissions (CO₂) generated by a passenger in a flight, for use in carbon offsetting programmes.

It provides information on the methodological approach and details the assumptions underlying the generic factors employed by the ICAO Carbon Emissions calculator. The methodology is provided in an open source format facilitating individual air carriers that may wish to customize it with their own data.

The document includes a general description of the method adopted by ICAO in order to estimate the CO₂ emissions of a flight (Item 2); the detailed calculation process implemented by the ICAO Calculator (Item 3); a description and analysis of the data inputs used (Item 4); a demonstration of the data coverage and sensitivity (Items 5 and 6); and the steps needed to be taken by a company wishing to customize the calculator with its own data set (Item 7).

2 Methodological Approach

The ICAO methodology employs a distance-based approach to estimate an individual's aviation emissions using data currently available on a range of aircraft types. In order to implement this methodology, ICAO uses the best publicly available data regarding fuel consumption and it is committed to continuously monitor and seek improvements in the data used, in order to obtain better emissions estimation.

The ICAO methodology has been designed to require a minimum amount of input information from the user regarding the particulars of the flight concerned. It employs industry averages for the various factors which contribute to the calculation of the emissions associated with the individual passenger's air travel. As passengers' aviation emissions are affected by continuously changing variables specific to each flight, it is necessary to develop average factors to account for the effect of these flight parameters. While these factors cannot be captured on a flight-specific basis, this methodology considers them for the purpose of developing a more robust estimation of flight emissions and educating the public and the industry as to how these factors affect an individual passengers' emission intensity.

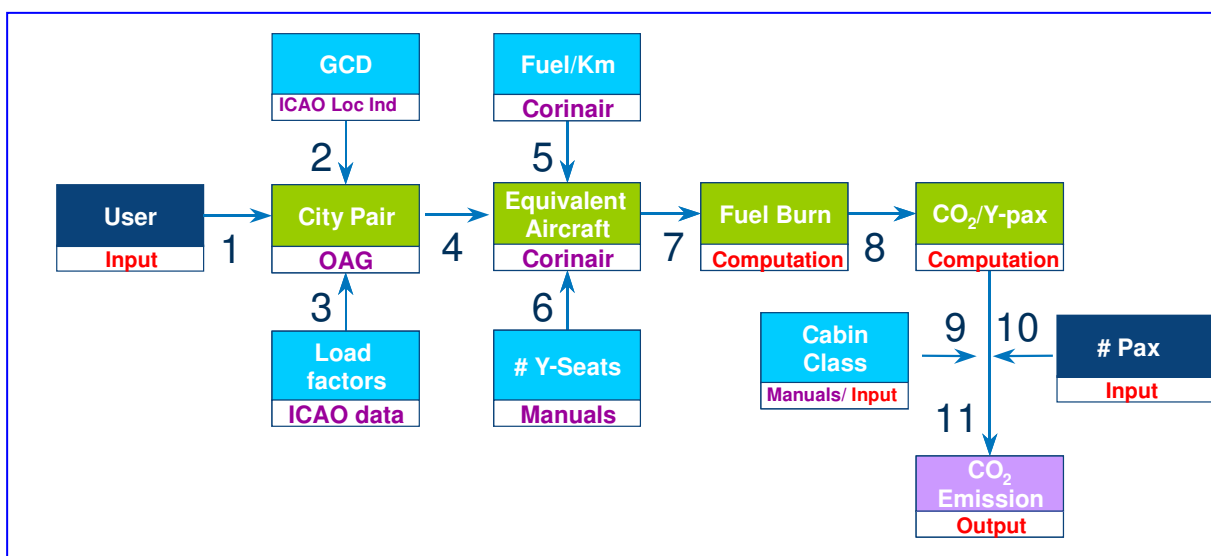
2.1 General Description of the Methodology

The ICAO Carbon Emission Calculator requires that the user input the airports of origin and destination for a direct through flight (i.e. a flight which does not have a change of the flight number). This is then compared with the published scheduled flights to obtain the aircraft types used to serve the two airports concerned and the number of departures per aircraft. Each aircraft is then mapped into one of the fifty equivalent aircraft types in order to calculate the fuel consumption for the trip based on the great circle distance between the airports involved in the journey. The passenger load factors, and passenger to cargo ratios, obtained from traffic and operational data collected by ICAO, are then applied to obtain the proportion of total fuel used which can be attributed to the passengers carried. The system then calculates the average fuel consumption for the

journey weighted by the frequency of departure of each equivalent aircraft type. This is then divided by the total number of economy class equivalent passengers, giving an average fuel burn per economy class passenger. The result is then multiplied by 3.157 in order to obtain the amount of CO₂ footprint attributed to each passenger travelling between those two airports.

3 Calculation Procedure

ICAO used this methodology to develop a Carbon Emissions Calculator using a database constructed from several data sources. From the diagram below, we identify the following information used as input of the calculator:



City Pair: Obtained from the airlines multilateral schedules database. The flight schedule data are based on the latest available information and are updated every three months.

GCD (Great Circle Distance): The distance between origin and destination airports is derived from latitude and longitude coordinates originally obtained from ICAO Location Indicators database.

Load Factors: The average generic factors considered for the purpose of this calculation are sourced from the Traffic by Flight Stage database (TFS) which collects air carrier city-pair specific traffic data by aircraft type produced on an annual basis, and domestic traffic and operational data, both collected by ICAO, as well as data based on the flight schedules published by the air carriers.

Fuel/Km: This information, per equivalent aircraft model, is obtained from the CORINAIR database, and expanded by ICAO to reflect the fuel consumption of regional jets.

Y-seats: This is the number of economy seats that can be fitted inside the equivalent aircraft. ICAO made use of a standard cabin layout (in terms of location of galleys, toilets and exits) for each reference aircraft. This fixed space was then fitted with an all-economy seating using a pitch of about 31/32 inches. This seating configuration was then compared with a mixed configuration involving business and/or first class row/seat combinations where, for the large wide bodied aircraft, business class seats have a 38 inch pitch, and those in first class have a 60 inch pitch. Examples of these layouts were obtained from the Manual on Airplane Characteristics for Airport Planning published on the Web by the aircraft manufacturers.

In simple terms, the general methodology used by the ICAO calculator can be described with the following steps, with references to the diagram below:

User input (1) – The user enters the origin and destination airports. The database is searched for all flights, direct or non-direct, serving that city-pair. However, the tool does not compute total emissions for journeys with different flight numbers (connecting flights). To do this, the user can choose to build a total by calculating each of the journey legs separately and adding them up.

Code share flights are treated as a single flight. This avoids a possible double counting of flight departures that would otherwise affect the calculations.

The origin and destination database includes individual routings for single flight numbers with multiple stops. Hence the passenger does not need to know, nor input the full itinerary of the flight.

Trip distance (2) – The ICAO Location Indicators database contains the longitude and latitude coordinates for the airports. From these coordinates the Great Circle Distance (GCD)¹ is then calculated and corrected by a factor depending on the distance between the two airports concerned (see section 4.2).

Traffic data (3) – A passenger load factor is assigned to the user-defined city-pair, based on the passenger load factor for the corresponding route groups. Load factor information is obtained from the database, based on 17 international route groups plus 5 domestic areas (see **Appendix A**).

Aircraft mapping (4) – From the scheduled flights database, the scheduled aircraft is identified and linked to the aircraft fuel consumption database EMEP/CORINAIR. When the scheduled aircraft is not in the database, the aircraft is mapped into one of the fifty equivalent aircraft types existing in the aircraft fuel consumption database. **Appendix B** provides details of how this mapping was done. This allows estimation of the total fuel use on each route serving the user-defined city-pair.

Fuel burn data (5) – The fuel burn to flight distance relationship is extrapolated from the Emissions Inventory Guidebook (EIG) prepared by EMEP/CORINAIR. The factors considered include passenger load factor, flight distance, the proportion of the overall payload represented by passenger traffic, cabin class flown, and type of equivalent aircraft

¹ The Great Circle Distance is the shortest path between two points on the surface of a sphere

flown. The amount of fuel used on a route is the weighted average of total fuel burnt based on the frequencies of the scheduled aircraft types flown.

Economy Class (Y) seat capacity (6) – From cabin floor plans obtained from the “Manual on Airplane Characteristics for Airport Planning”, which is developed by manufacturers to provide necessary data to airport operators and airlines for airport facilities planning, the maximum number of Y-seats that can be fitted per equivalent aircraft is determined. This “virtual” all economy configuration later allows the computation of cabin class factors (steps 9 & 10).

CO₂ per economy passenger (7 and 8) – Using the trip distance, equivalent aircraft fuel consumption, passenger to seat load factor and passenger to freight load factor for the route group, and the number of Y-seats, the methodology calculates the CO₂ associated to each passenger, as follows:

$$\text{CO}_2 \text{ per pax} = 3.157 * (\text{total fuel} * \text{pax-to-freight factor}) / (\text{number of y-seats} * \text{pax load factor})$$

where

Total fuel = The weighted average of the fuel used by all flights departed from the origin airport in order to reach the destination airport. The weighting factor is the ratio of number of departs for each equivalent aircraft type, to the total number of departs.

Pax-to-freight factor = is the ratio calculated from ICAO statistical database based on the number of passengers and the tonnage of mail and freight, transported in a given route group

Number of Y-seats = the total number of economy equivalent seats available on all flights serving the given city pair

Pax load factor = the ratio calculated from ICAO statistical database based on number of passengers transported and the number of seats available in a given route group

3.157 = constant representing the number of tonnes of CO₂ produced by *burning* a tonne of aviation fuel.

Cabin class (9 and 10) – Depending on user selection, a multiplicative cabin class factor is applied to adjust the CO₂ per Y-passenger, on those routes where multiple class passenger services are available.

Passenger CO₂ output (11) – The estimated quantity for the carbon emission.

4 Data Sources

This methodology seeks to distribute the emissions between the passengers travelling in different cabin classes, and between passenger and cargo, in an equitable manner. This section details how the various contributing factors come together to accomplish this result.

4.1 Fuel Data

In keeping with the latest recommendations of the IPCC contained in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories a modified Tier 3A method is used which is based on actual movement data. The 2006 Guidelines suggest the EMEP/CORINAIR Emission Inventory Guidebook² (EIG) as the base of commercial aviation fuel burn and emission information. The Guidebook includes an accompanying workbook which details fuel burn and emissions associated with discrete mission distances for 44 equivalent aircraft types. CORINAIR fuel database uses modelled data derived from the aircraft performance model PIANO³. It uses equivalent aircraft types and, due to the age of the study, lacks fuel data for the more recent aircraft types and their derivatives.

In order to implement the methodology the database used by ICAO takes the fuel burn to distance flown data provided by CORINAIR and extends some aircraft ranges by extrapolation using a linear regression. This approach was chosen since the fuel consumption curves approaches a linear relationship to distance when considering medium and long haul flights. ICAO also expanded the data by adding fuel burn information, provided by the manufacturers, for 6 regional jets.

While the main objective of CORINAIR is to support the development of National GHG Inventories, this methodology seeks to allocate a proportion of emissions associated with a given equivalent aircraft type operating between given city pairs to individual passengers. In this context, it is considered appropriate to use CORINAIR data as long as the CO₂ calculation is performed on an average fleet basis per city pair and not on an individual aircraft basis, and noting that in many cases the calculation is near $\pm 10\%$. This variation in data is largely due to the aircraft models currently included in CORINAIR and mapping these aircraft to the actual operating aircraft models not included in CORINAIR⁴.

While it is well known that most air carriers have detailed information in regards to their fuel consumption and fuel efficiency, this information is not publicly available. At present, it was not possible to identify any suitable public alternative data source making CORINAIR the best publicly available data source for the purpose of the ICAO methodology.

The dataset obtained from the modified CORINAIR, listing the 50 equivalent aircraft data, is included in the **Appendix C** of this document.

² EMEP/CORINAIR Emission Inventory Guidebook (http://reports.eea.europa.eu/EMEP_CORINAIR4/en/page002.html)

³ <http://www.lissys.demon.co.uk/>.

⁴ For example, to model a B737, CORINAIR contains two choices of older models, the B737-100 and B737-400. For some city pairs this may adequately model the specific aircraft servicing the city pair. However, on other city pair routes that operate mainly newer more fuel-efficient B737 models (B737-600/700/800/900) CORINAIR would overestimate the fuel burn and CO₂ production

4.2 Trip distance

The methodology proposes the use of the Great Circle Distance (GCD) between the input airports, in order to get the fuel used, and thus estimate the CO₂ emissions.

GCD is by definition the shortest distance between two points on the surface of a sphere. This distance can be calculated by using the geographical coordinates of the two points concerned. The coordinates for the airports involved are obtained from the ICAO Location Indicators database. Once the GCD is then calculated it is corrected by a factor depending on the distance between the two airports concerned.

The correction factor is needed in order to include the emissions of distance flown in excess of the GCD, stacking, traffic and weather-driven corrections. According to EIG, the actual distance flown compared with GCD that is given in the scheduled flights timetable may vary up to 11% in Europe (ANCAT/EC2 1998).

Stopovers, connecting flights and refuelling stops impact on the overall flight distance as they divert from the straight line representing the GCD. The implementation of the ICAO methodology, carried by ICAO to calculate the trip distance takes into account the additional mileage resulting from stopovers and refuelling stops associated with a sequence of flights identified by a single flight number. However, for a sequence of flights with different flight numbers (connecting flights) the trip distance is calculated separately for each individual flight segment.

The table below shows the GCD correction factor used.

GCD	Correction to GCD
Less than 550 Km	+ 50 Km
Between 550 Km and 5500 Km	+ 100 Km
Above 5500 Km	+ 125 Km

4.3 Aircraft type

The CO₂ emission is calculated from the fuel burned by the aircrafts serving a given route. The scheduled aircraft is identified from the scheduled flights database, and mapped into one of the fifty equivalent aircraft types existing in the aircraft fuel consumption database (**Appendix C** provides details of how this mapping was done). The aircraft types that are cannot be mapped are excluded from the calculations. Leaving out aircraft types or variants that are not in the database would at present only have a minor influence on the final result.

4.4 Passenger Load Factors and Passenger to Cargo Factor

As this methodology is intended to assess the passenger's aviation emissions it is necessary to deduct the flight emissions associated with the freight and mail carried on the flight from the total. This calculation will be performed on a revenue mass basis using historic freight and mail numbers specific to the city-pair being considered.

The data are sourced from the ICAO TFS dataset which contains totals of number of seats and passengers, tonnes of freight, and tonnes of mail carried. In order to develop an average freight allocation an average passenger mass with baggage is assumed as 100 Kg, plus a 50 Kg add-on to account of the onboard equipment and infrastructure associated with passenger use (for example, the weight of seats, toilets, galleys and crew). The total mass is then established as:

$$[((\text{No. Passengers} \times 100 \text{Kg}) + (\text{No. of seats} \times 50 \text{Kg})) / 1000] (\text{tonnes}) + \text{Freight (tonnes)} + \text{Mail (tonnes)}$$

Based on the historical traffic data it is then possible to establish the proportion of freight and mail mass in relation to the total mass calculated by the formula above. The resulting proportion is the fraction of the flight emissions for which the passengers should not be held accountable for. The TFS data is updated annually by ICAO for each one of the 17 international route groups (see **Appendix A**).

4.5 Cabin class

The cabin class correction factor is used only on equivalent aircraft types that support such differentiation, and on flights of more than 3,000 Km. It is based on the principle that premium seats occupy a larger space than that of an economy seat; therefore the same cabin configured with premium seat arrangements carries fewer passengers than an all-economy layout.

In order to define the cabin class correction factor, each representative aircraft has been assigned a standard all-economy class layout in order that the reduced capacity resulting from premium seating accommodations is recognized for the additional share of flight emissions associated with these seating arrangements. This cabin class correction factor is based on the principle that premium seats occupy a larger footprint than that of an economy seat; therefore the same cabin configured with premium seat arrangements carries fewer passengers than an all-economy layout. While it is not possible to account for all possible configurations of a given aircraft the cabin class correction factor serves to educate the user as to the environmental effect of their travel decisions. For this reason generic cabin class factors have been estimated.

The methodology employs a simplified approach by using two cabin class factors (“economy” and “premium”) when allocating emissions to passengers, with a ratio of 1:2.

5 Discussion of Sensitivities

In any modelling exercise the desire for accuracy is moderated by the level of complexity the analyst is willing to accommodate. In the case of the ICAO methodology an attempt has been made to account for the principal factors which define an individual’s aviation carbon emission footprint while assessing each at a level which recognizes the inherent uncertainty underlying many of the assumptions embedded in this approach.

Great Circle Distance – while it is understood that air travel does not occur in a straight line between two points, actual flown distance to be collected from the air carriers, or

from a more accurate trip distance database showed to be not feasible for the time being.

Representative Aircraft – as aircraft typically share similar performance characteristics, if designed for similar operation, the adoption of a representative aircraft approach is both necessary and reasonable given the level of detail available. It is recognized that the CORINAIR data lacks representation for several aircraft types. It is also recognized that there are considerable differences in fuel consumption between aircraft belonging to the same aircraft type variant, dependent on many factors such as age and airline specific configuration, including engines. However, at present, it was not possible to identify any suitable public alternative data source making CORINAIR the best publicly available data source for the purpose of the ICAO methodology.

Cabin Class Factor – it is recognized the offering of several seat configurations, and different classes of service among air carriers. The ICAO Carbon Emission calculator does not use a specific aircraft configuration; instead, it uses the equivalent aircraft approach that represents the actual equipment in use. Due to the general nature of this methodology it was decided to use a simplified approach, restricting the cabin classes to two: one representing the economy class, and the other representing the premium classes (premium-economy, business, and first).

Passenger Load Factor – average passenger load factors are calculated on a route group basis for international flights and on a regional basis for domestic flights. The data is obtained from the reported data sent by states to ICAO, and it tends to change at every semi-annual update.

Passenger to Cargo Factor – average cargo factors on passenger aircraft are calculated on a route group basis for international flights and on a regional basis for domestic flights. The data is obtained from the reported data sent by states to ICAO, and it tends to change at every semi-annual update.

Fuel consumption per aircraft type – throughout the design of this tool, the intention was to default to the best publicly available information. While it is well known that most air carriers have detailed information in regards to their fuel consumption and fuel efficiency, this information is not publicly available. At present, it was not possible to identify any suitable public alternative data source making CORINAIR the best publicly available data source for the purpose of the ICAO methodology.

6 Maintenance Requirements of the ICAO Methodology

In order to support the continued improvement and adoption of the ICAO methodology various data components will require a regular update by ICAO and be provided to users seeking to implement the ICAO methodology. These include:

ICAO traffic data – to be analyzed and updated on a semi-annual basis;

Air carriers scheduled data – In order to calculate the composite city emissions city-pairs data are to be updated on a semi-annually basis to reflect the schedules operated by the air carriers during the period;

Generic Aircraft Mapping – To account for changes in the equipment operating in the industry ICAO will complete a review of the aircraft types listed in the scheduled flights database and the TFS and publish a reference document showing the corresponding mapping to representative aircraft type for all in service aircraft type.

Aircraft Fuel consumption – In order to keep up to date information about new aircrafts types and technology improvements adopted by the industry, ICAO will update the fuel per kilometre information for the several aircraft equivalent models, as soon as new information is made available by aircraft manufacturers and air carriers.

7 Options for Carrier Specific Accuracy Improvements

As ICAO recognizes the additional benefits, which more detailed air carrier specific data can provide, the ICAO methodology is intended to be open source for carriers that are considering their own offset programmes and able to receive enhancements to the quality of data employed for the calculations. Possible carrier specific improvements include:

Fuel Burn – Given the air carriers flight planning requirements in terms of efficiency and safety it is anticipated that air carriers will be interested in employing more robust data to the fuel consumed on their operated flights.

Cargo Carried – An air carrier may use its own cargo factor so long as the level of aggregation is provided in accompanying documentation.

Passenger Load Factor – An air carrier may use their own passenger load factor so long as the level of aggregation is clear in accompanying documentation.

Aircraft Configuration – On account of the generic nature of this methodology an air carrier may wish to implement fleet specific data on the aircraft operated in its service.

Appendix A

Factors per Route Group

Route Groups		Pax Load Factors		Pax to freight Factors	
		Wide Body	Narrow Body	Wide Body	Narrow Body
1	Between North America and Central America/Caribbean (NC)	74.60%	72.90%	87.23%	98.40%
2	Between and within Central America and the Caribbean (LC)	56.30%	60.20%	86.38%	98.90%
3	Between Bermuda, Canada, Mexico and the United States (LNM)	65.40%	71.60%	81.84%	98.40%
4	Between North Am/Central Am/Caribbean & South America (NCS)	76.60%	69.50%	74.67%	96.40%
5	Local South America (LS)	60.10%	61.20%	72.44%	91.90%
6	Local Europe (LE)	67.00%	71.00%	79.29%	98.20%
7	Local Middle East (LM)	37.00%	71.30%	70.24%	100.00%
8	Local Africa (LA)	50.00%	47.50%	67.69%	99.40%
9	Between Europe and Middle East (EM)	71.90%	71.10%	67.21%	98.00%
10	Between Europe /Middle East and Africa	77.50%	67.20%	73.25%	97.00%
11	North Atlantic	80.80%	77.80%	72.94%	97.30%
12	Mid Atlantic	80.90%		81.05%	81.00%
13	South Atlantic	87.80%		74.37%	74.40%
14	Local Asia	68.90%	67.00%	72.16%	91.80%
15	Between Europe/Middle East/Africa and Asia	79.10%	69.70%	69.65%	93.10%
16	North & Mid Pacific	80.20%		78.81%	78.80%
17	South Pacific	76.60%	62.40%	80.99%	92.80%

Appendix B

Equivalent Aircraft Mapping (based on aircraft currently flown)

AIRCRAFT	EQVT	AIRCRAFT	EQVT	AIRCRAFT	EQVT	AIRCRAFT	EQVT
717	100	744	744	CRJ	CR2	A40	F50
E90	100	74E	744	CR1	CR2	F50	F50
E95	100	747	747	CR2	CR2	JST	J31
100	100	74M	747	ERJ	CR2	J31	J31
AR1	146	74L	747	ER3	CR2	J32	J31
AR7	146	741	747	ERD	CR2	J41	J41
ARJ	146	742	747	ER4	CR2	EM2	J41
AR8	146	743	747	FRJ	CR2	IL8	LOF
146	146	74D	747	CR7	CR7	M80	M80
141	146	ILW	747	CRA	CR7	73J	ND
142	146	757	757	CR9	CR9	BE20	BE20
143	146	752	757	E70	CR9	DC8	DC8
310	310	75W	757	EMJ	CR9	F406	F406
313	310	753	757	E75	CR9	LOF	LOF
318	320	T20	757	F70	CR9	SC7	SC7
32S	320	AB3	767	YK4	CR9	B350	B350
319	320	AB6	767	D10	D10	LOH	LOH
320	320	AB4	767	D1C	D10	ND	ND
321	320	767	767	M11	D10	M81	M80
330	330	762	767	L11	D10	M82	M80
332	330	763	767	L10	D10	M83	M80
333	330	764	767	L15	D10	M88	M80
340	340	777	777	D38	D38	M87	M80
342	340	772	777	707	DC8	M90	M80
343	340	77L	777	IL6	DC8	I14	S20
345	340	773	777	IL9	DC8	S20	S20
346	340	77W	777	DC9	DC9	CS2	SC7
727	727	AN4	AN6	D93	DC9	DHT	SC7
72M	727	AN6	AN6	D95	DC9	YN2	SC7
721	727	A28	AN6	D9S	DC9	SF3	SF3
72S	727	CV5	AN6	YK2	DC9	ND2	SH3
722	727	YS1	AN6	DH7	DH7	SH3	SH3
72A	727	YN7	AN6	ATP	DH8	SH6	SH6
TU5	727	AT3	AT4	CS5	DH8	D28	SWM
737	732	ATR	AT4	DH8	DH8	SWM	SWM
73M	732	AT4	AT4	DH1	DH8	GRS	SWM
73S	732	AT5	AT4	DH2	DH8	BEC	NA
732	732	AT7	AT7	DH3	DH8	DHP	NA
73A	732	B11	B11	DH4	DH8	DHS	NA
733	734	F24	B11	DHO	DHO	PAG	NA
73C	734	BET	BE20	DHL	DHO	DHC	NA
734	734	PN6	BE20	PL2	DHO	ACD	NA
73Q	734	BE1	BES	EMB	EMB	BE2	NA
735	734	BES	BES	L4T	EMB	BNT	NA
736	734	BEH	BES	HS7	F27	BNI	NA
73G	734	DHB	CNC	FK7	F27	CNA	NA
73W	734	CNC	CNC	F27	F27	PA2	NA
738	734			F28	F28	AGH	NA
73H	734			TU3	F28	BH2	NA
739	734			BE9	F406	NDE	NA
						S61	NA
						S76	NA
						380	NA

NA = Equivalent mapping is Not Available

