ICAO's Metric for CO_2: Abandoning Science for Expediency

An open letter

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ICAO is presently finalising a metric proposal intended to quantify aircraft CO_2 emissions in future legislation. The author warns that the form of this metric is fundamentally flawed, unfit for purpose, and carries great risks for both the environment and the industry if not challenged prior to formal adoption. Gross technical blunders are about to be incorporated into key global policies. This letter is urgent and unapologetically candid in its views, which are those of the author alone.

• The entrenchment of a catastrophic policy

During May 2012 in Paris, ICAO's Committee on Aviation Environmental Protection (CAEP) internally established the form of a metric that will potentially quantify CO_2 emissions of aircraft for future legislation. After an extraordinarily long effort, the result is little more than a contorted version of fuel mileage. ICAO defines a 'magic number' postulated at a set of opaque conditions. This fails to account for even rudimentary determinants and neither reflects nor can influence the underlying drivers of aviation CO_2 emissions, yet final approval is expected to take place in July in St Petersburg.

ICAO's metric is *(fuel burn per unit distance)* divided by *(a measure of cabin area),* evaluated at three points extrapolated solely from maximum takeoff weight (MTOW, see appendix).

Fuel burn per unit distance is obviously not a unique number for any aircraft; it is a transient quantity at a spot flight condition. It varies substantially with instantaneous weight, altitude, speed and other assumptions. It is also evident that in a broad sense, 'large' or heavy' aircraft are likely to produce poorer numbers than 'small' or 'light' aircraft. ICAO attempts a superficial concession to reality through obtuse statistical adjustments to its metric based on nothing more than cabin size and demonstrably erroneous weights.

ICAO is also tasked to set a sharp Pass / Fail standard whilst somehow reflecting the abstract notion of 'technology', no quantification of which can be given. It is impossible to overstate the harmful consequences of this quasi-theological approach. An absolutist division of aircraft into outright 'good' or bad' using flimsy arguments is a schoolboy howler that invites the practical failure of the standard.

It may be that ICAO is hoping to emulate the effectiveness of its noise standard, which was indeed successfully defined on a Pass / Fail basis at simple point conditions. This ignores a fundamental difference: Noise can be meaningfully reduced by focusing just on worst-case scenarios. CO_2 (i.e. fuel burn) on the other hand cannot be correlated to unique cases. It derives from the integrated or 'summed up' performance of a complex system. It depends on attributes that vary throughout any flight and in any fleet and that ICAO conspicuously ignores.

• What will be said here

This article suggests that malformed rules based on an ab-initio unsound metric are the last thing that the environment, the aircraft industry, or the airline industry need at this turbulent time in history. It also argues strongly that the problem of creating a true and effective CO2 metric is in fact both fully tractable and indeed in essence already resolved, with a clear route to implementation. It offers likely reasons why ICAO has apparently chosen to avoid a transparent scientific path and focus instead on what are largely side-issues, non-causal correlations or placebos. It also sets out in some detail alternatives that can fairly reflect true CO2 emissions, to the long-term benefit of all parties, without usurping political decisions or dictating any specific form of mitigation measures or legislation.

• Why this opinion carries some weight

The author created the 'Piano' aircraft analysis software which has been central in the work of the ICAO environmental process since the 1990s. Piano constitutes the aeronautical engineering core that is used to quantify CO2 emissions in two out of four Greenhouse Gas (GHG) Aviation Models formally approved by ICAO (AERO2k and FAST; the other two models, AEDT and AEM/BADA, rely on measurements of actual flights but even so also use, or have used, Piano to improve aspects of their implementation). See *“Guidance Material for the Development of States' Action Plans. Towards the Achievement of ICAO's Global Climate Change Goals”* and additional references at the end of this document. More recently ICAO group leads requested and received from the author permission to use Piano data as their "secondary dataset" while finalising metric deliberations. The term "primary dataset" referred to manufacturer-provided data which mostly failed to materialise. The author has no position within the ICAO CO2 process and seeks none, but the technical essence of the process relies extensively on Piano and its database.

• Modelling the inconvenient essentials

Basic science dictates that when carrying a payload over a distance, three essentials determine the fuel burn, and therefore CO2 emissions: Aerodynamic drag, empty weight, and engine characteristics. These three 'elephants in the living room' have been consistently ignored or marginalised by ICAO. It is however impossible to produce meaningful assessments of aircraft behaviour without acknowledging the incontrovertible primacy of these factors.

Generating and putting together such fundamentals in a coherent form is precisely what Piano has been doing for more than two decades. A combination of analytical methods and reliable real-world information yielded a calibrated database of aircraft that constitutes a de-facto standard. Products of the major manufacturers have been accurately modelled for CO2 purposes under all relevant operational scenarios. Those of lesser players, business jets or turboprops, are currently less perfectly represented but still furnish close estimates.

Although the industry is clearly entitled to protect knowledge relating to the design and construction of aircraft, it is deeply wrong in not being transparent about what its aircraft do. Drag, empty weights and fuel flows are all regularly deduced or variously established by all major industry competitors and by all conceivable means. This is the essential scientific information that directly and necessarily decides CO2 emissions; It is not, and cannot be claimed to be, proprietary to the detriment of science and the global environment. Physics cannot be subject to unsupportable claims of commercial sensitivity. Simply knowing what an aircraft can do does not in any way enable anyone else to build that aircraft. Suppressing scientific quantification is unnecessary, unwise and ineffective, as well as unseemly. Despite the interminable blandishments of public relations pundits proffering meaningless percentages without baselines, verified aircraft characteristics circulate ever more widely and faster both within the industry and outside given the interconnected nature of the modern world. A culture of secrecy achieves nothing more than harming the credibility and prospects of the industry itself.

Whatever the attitude of the industry may be, whether with or without the cooperation of manufacturers, it is nowadays perfectly possible to generate very accurate fuel burn models of modern commercial aircraft, and this is a task that has already been largely achieved.

ICAO's central reliance on Piano for its internal work is a tacit acknowledgement of this reality, yet ICAO ultimately fails to embrace these facts and simply retrogresses to voodoo statistics for its formal metric.

The modelling of aircraft for the purposes of accurately quantifying their CO_2 emissions is not an option; it is a scientific necessity and an eminently doable task. A legislative standard that fails to model the very things it purports to assess arguably constitutes nothing less than scientific fraud. It is surely the most conspicuous triumph of political expediency over science.

• The worst of all possible outcomes

Observing the ICAO process from its periphery over an extended period exposes the committee dynamics that cause eminent groups of thinking, educated and capable professionals to act together to produce the worst possible result. ICAO is a loose organisation of participants with conflicting interests. Everyone is wary of everyone else, and environmental groups, manufacturers and airline groups all seem to be entrenched in narrow positions. A March 2012 slide presentation by one particular airframe manufacturer brandished these extraordinary bullet points:

- "*Our ultimate Goal is to* ***design*** *the CO2 standard so that it does not interfere with the market*"
- "***Exclude all*** *commercially important parameters from the metric system of the standard to eliminate its* **potential** *to interfere with the market*"
- "*Parameters to be* ***Excluded****: Payload, Range ...* etc."
- "*In case they need to be included,* ***Neutralize*** *it!!*"

(all bold emphases and exclamations are per the original.)

It must be said clearly that the above oeuvre did not find support within the manufacturers' group to which it was presented, but its points nonetheless indicate the level of some of the argumentation. They are certainly well reflected in the resulting castrated standard. As in many historical parallels, the obvious and real danger is that irrational fears and intransigent positions have by themselves caused the worst possible outcome for all. This will strongly encourage counter-productive forms of unpredictable gaming to follow a meaningless target, almost certainly at the expense of real-life CO_2 increases. Given the absurd nature of the metric, the entire process will either have to be side-stepped by setting a pass / fail bar so low as to affect practically nothing, or otherwise risk unpredictable damage.

Yet the reality is that a well-implemented scientifically valid standard would be much more of a boon than a hindrance for the industry, providing great scope for new and diversified designs and encouraging effective competition whilst simultaneously having a real diminishing effect on CO_2.

As an aeronautical engineer and technical insider the author has the deepest respect for an industry brimming with extremely competent professionals, some of them personal friends, whose efforts allow us all to fly around the world safely and to operate a global economy. But if a potential opportunity for all becomes instead the prelude to yet another unnecessary catastrophe, industry leaders that spurned a scientific approach and elementary transparency in favour of aggressive non-cooperation will have much to answer for in the long-term damage that they will inflict to their very own industries.

• An example of what can be done with modelling

Modelling the CO_2 production of individual aircraft types before pronouncing judgment upon them is a logical necessity. Only when this fact is unambiguously acknowledged (rather than subverted) can the issue of CO_2 emissions be addressed in a reasoned manner.

The real determinants of CO_2 today are a myriad of commercial choices and hard-nosed business decisions taken within the industry by a multitude of manufacturers and operators. These dictate aircraft sizing and route selections, utilisation and comfort / furnishing levels. CO_2 is certainly not decided by some fuzzy concept of 'technology' that fancifully always improves with time. Technology comes in all guises and at its own pace and can penalise as well as aid in CO_2 emissions. Whenever it's for real, technology will be automatically reflected in the fuel burn numbers coming from the validated aircraft models. Better mousetraps will not materialise by virtue of exercises in metric numerology.

It is impossible to dissociate from each other the mutual influences and commercial interdependencies of manufacturers and operators. These have to be treated as one complex whole that unavoidably produces CO_2 because humanity needs to carry payloads over distances.

CO_2 emissions occur in the context of a basic playing field, that is a grid of distances and payloads covering global transport capabilities of any tonnage anywhere, up to halfway around the world. Consider such a grid, with distance along one axis (say from 100 nm up to 10800 nm in fine resolution) and payload along the other (say from 0.5 to 150 tonnes). At each point, determine the fuel burn of all existing aircraft types capable of executing that mission and assign the best number to that point. This forms a 'reference grid' or idealised state-of-the-art for a notional optimal global fleet.

It is now natural to quantify CO_2 at the operator level for each aircraft type and route combination. All necessary information is accessible. True fuel burns can be derived from the model and compared to the 'reference grid' as follows: Say an operator has a total of n (aircraft type / route distance) combinations, so each number from 1 to n represents a unique pairing. Each also connotes a nominal payload at the operator's published seating configuration, say at full load factor (so we get corresponding payloads p1... pn, many of these being the same, or all if it's a single-type operator). One can (and should) use actual operator OEW (operating empty weight) in preference to a 'typical OEW' (the latter may still enter the reference grid definition). Let the resulting fuel burns be f1, f2... fn, for nominal payload and great-circle distances. Of course n may be quite large, but that is no problem; automating the calculations is easy. Finally, let the corresponding 'reference grid' fuel burns be g1, g2... gn, recalling that each of these can come from a different type at each point of the grid.

Assuming the total annual distances flown by the operator (say last year) for each type-route pairing are d1... dn, we now simply add up the tonne-kilometres, adjusted for off-optimum fuel burn and presented as a fraction of the total, i.e:

$$(p1\ d1\ f1/g1 + p2\ d2\ f2/g2 + \ldots + pn\ dn\ fn/gn) \ / \ (p1\ d1 + p2\ d2 + \ldots + pn\ dn)$$

This is just one of many possible figures of merit for the operator and fully reflects his aircraft choices. (The lower the better, ideal score approaches 1 if the operator uses the 'perfect plane' for each route.) The figures require no data collection by the operator and are fair and direct reflections of CO_2 reality. Overall burns will of course be noticeably higher due to off-great-circle routing, winds, disrupted schedules, degradations etc, but that is of no concern as these factors affect the system universally with little or no bias. The annual miles flown for each aircraft / route pair can be derived directly from published flight schedules or publicly available sources.

A multitude of similar modelling formalisms can be readily conceived, the above being merely one example. Let us now examine the contrasting consequences of the ICAO and modelling approaches.

• The irrational nature of ICAO's proposed metric

It is not clear how ICAO's Pass / Fail metric proposes to influence either aircraft design or market behaviour towards a reduction of CO2. Aircraft sizing decisions and fleet purchases are both based on strategic and commercial considerations that often result in far from CO2-optimal compositions. An operator in need of a long-haul aircraft might be induced through price incentives to also use the type (or version thereof) in short-haul routes. Or alternative types from the same manufacturer may be offered as part of the same deal, say substituting medium-range jets in lieu of more suitable turboprops from some other manufacturer.

As an example of the dangers of the metric, an operator's purchase of Boeing 787s under any utilisation scenario is invariably a positive. Even operating a proportion of his fleet over 300 nm routes, where the type is by any credible measure CO2-inefficient, he could benefit from retiring some existing commuter aircraft that do the job with far fewer CO2 emissions but nominally fail the ICAO test. This perverse behaviour of the metric contrasts strongly with the modelling approach advocated above. Now, the operator is correctly and fairly rewarded for using the very same B787s efficiently over long routes in preference to (say) A330s, where the latter type does indeed commonly produce more CO2. However, the model also automatically penalises him if he inappropriately operates the type over short hops instead of, say, a B737 or Q400. That is precisely as it should be.

In ICAO's definition of *(fuel burn per unit distance) / (floor area parameter)*, the precise details of the floor area parameter receive considerable attention. Compelling issues are clarified, such as whether the portion of area added by the outward curvature of the rear pressure bulkhead dome should be included (apparently the answer is no). Whilst saluting such admirable meticulousness, let us focus instead on certain other aspects of this definition that are less well elaborated:

• Pioneering antigravity

Incredibly, the ICAO metric fails to account for the physical weight of the aircraft. This verges on the surreal, so is worth repeating: The proposed ICAO metric ignores aircraft weight. It posits three so-called 'weight levels' concocted exclusively from MTOW and nothing else. But MTOW is not the aircraft weight, it is a regulatory safety limit when loading up the aircraft. Operational fuel burns (and CO2) are utterly insensitive to this constant. Sizing correlations between design MTOW, range and fuel burn constitute obvious trends during the design phases of an aircraft, but in no way can that be extrapolated across to existing, unconnected, certificated aircraft. That would imply total uniformity of design (and presumably declaring everybody equal does rather remove the need for a metric). In any operation, for any type, the physical weight that decides CO2 is the OEW. This is a mathematical necessity; it is not one of many weights that matter, it is the *only* one that matters. OEW uniquely determines CO2 for any combination of payload, distance, and set of operational rules and reserves. If you don't have an OEW, you have precisely nothing. MTOW and other regulatory limits like MZFW simply do not enter in the calculation of fuel burn (CO2). Such safety boundaries impact a mission *only* in the sense of determining whether it is permissible or not (for example through field limitations or simply because TOW must not exceed MTOW). It is physically impossible to divine a meaningful weight for CO2 assessments from certification restrictions alone, as ICAO's metric implicitly purports to do. Using MTOW as a weight determinant of CO_2 is scientifically, and surely also legally under any rational system, utterly indefensible.

Consider two aircraft sharing the same geometry (thus in essence aerodynamics) and the same engine, both certificated to the same MTOW, but each designed and built around substantially different materials by manufacturers with dissimilar capabilities. They will necessarily produce very different amounts of CO_2 for the same payload over the same distance for all missions that they share (having different OEWs), yet ICAO's metric totally fails to distinguish between them. This is apparently a technology-focused metric with scant regard indeed for materials and structures.

Having been presented with ICAO's ostensible weights, the manufacturer is allowed to provide a 'fuel burn per unit distance' at unspecified flight conditions of his choice. The associated 'optimal' choices of Mach number and altitude will be neither mutually comparable between types nor transparent. At the end of the calculation, ICAO's metric thus yields an obscure semi-mystical number that cannot be consistently associated with any specific aircraft qualities, let alone used to quantify CO_2 emissions.

• Confronting responsibilities

To return to modelling: When generating validated models, a natural division of certification data sources arises. The airframer is clearly the prime source of aerodynamic characteristics (technically, a form of 'drag polar') and the engine manufacturer essentially provides engine characteristics (a form of 'engine deck'), with mutual interaction as necessary. Weight-related responsibility however resides with the operator, noting that a precise knowledge of true OEW constitutes an existing operational loading requirement (not a single flight can operate legally without it) and therefore actual fleet OEW merely needs to be formalised and published as a CO_2 certification quantity. It is an incontestable reality that furnishings are regularly added in quantities that overwhelm manufacturers' weight reduction efforts. For example, whilst Airbus publicly quote an 'estimated OEW' for the A380 of 270 tonnes (Airbus-AC-A380-20111101.pdf), certain operators with low-density cabins regularly function at known OEWs of 303 and 306 tonnes.

A common pretext for avoiding data provision responsibilities is to invoke various purported technical complexities of the modelling process. This is no more than a red herring, and it is perfectly possible to work with a variety of formats and engineering approaches (as Piano does) provided the will to cooperate exists. Given an absence of cooperation it then becomes incumbent on the certification authorities to make conservative assumptions during modelling in fairness to all participants, a rationale likely to produce results.

• The effectiveness of modelling

There is no simplistic, coercive 'Pass / Fail' under the modelling approach. The figure of merit accurately reflects the true CO_2 credentials of any aircraft + operator combination and can be used directly to incentivise the market through credits, fines, or taxation. The operator can strongly influence the figure through his aircraft choices. The manufacturers are strongly affected as an natural consequence through the operator's purchasing decisions.

The entire system exerts influence correctly by default, with no need for special pleading. Key decisions on comfort levels or speed or route lengths will all automatically impact the figure of merit. Each operator makes his own financial judgments as usual, including the cost of his CO_2 emissions. He decides whether the money-making potential of an extra 6" of cabin width is worth the impact on his figure of merit (if a specific type burns more than another that has a smaller fuselage diameter). He decides whether serving a route with a faster aircraft is profitable enough to counter any CO_2 penalty. Or if carrying a shower with one tonne of water over 7000 nm can attract enough high-value customers to offset the hit. Every such decision is ultimately reflected in the figure of merit. There is no possibility of being 'creative' with optional certification weights or other artificial distortions. Gaming becomes impossible.

In essence, commercial pressures are simply shifted nearer to environmental pressures, to a degree politically controlled by the size of the incentive / penalty. A CO_2 reduction is an absolutely unavoidable consequence. Nobody has lost any design freedom. Nobody is told what to buy or sell. Nobody needs to be neutralised or exterminated. Competition and the market survive unfettered.

Evidently, any modelling approach presupposes the existence of a common reference tool around which aircraft models can be calibrated to common standards. Such a tool exists and has a proven 20-year track record. Given the critical need for full transparency, a formally adopted reference tool should in principle enter the public domain and exclude external commercial influences.

In general, the proposed style of assessment can be applied at many levels. A case can be made for creating a separate 'reference grid' for pure freighters, a straightforward task. Modelling may be centered on alternative groupings, geographical classifications (transatlantic, transpacific, US domestic, etc.) or aircraft classes (turboprops, medium haul etc) defined in various fluid ways (and arguably putting the onus back on the manufacturers more directly). It seems unlikely that any of these would work as well as the end operator concept, but the point is that these are political decisions that can and should be discussed by ICAO. It is lamentable that instead of focusing on such policy matters, the process sofar appears to have exhausted itself on obstinately evading both basic science and its global responsibilities, yielding little more than an unrepresentative and dangerous metric.

Finally, a modelling approach is transparent and scrupulous, allowing long-term flexibility and vital room for corrections or adjustments. Real-life issues can be addressed; for example, fleet age could be included via performance degradation data regularly collected by operators. The proposed ICAO metric represents the antithesis of this scientific ethos. It would enshrine into law and inflict on future generations a monstrous monolith of monumental inexactitude.

• In conclusion

The key message is that effective metrics based on validated aircraft models are entirely workable and open the road to solutions that reduce CO_2 emissions correctly, without interfering in policy decisions. In contrast, the makeshift proposal devised by ICAO is an unsafe public placebo that utterly fails in its purported intent. Different aircraft emit CO_2 differently in transporting specific payloads over specific ranges. ICAO's CO_2 metric is unable to reflect this fact, measures nothing real, and can offer nothing real.

The author is an aeronautical engineer with no political agenda and (despite this letter) would rather avoid controversy. But the long-standing link between Piano and the ICAO CO_2 process is significant. Given the prodigious global implications of future aircraft CO_2 legislation, deeply wrong decisions should be challenged before it is too late. Remaining silent at this critical time was not a tolerable option.

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• Appendix - The current metric proposal

Metric = $1/(SAR*RGF^{0.24})$

SAR = specific air range
RGF = reference geometric factor, a 'measure of fuselage size' (basically cabin floor area)

3 test points with equal weighting at optimum conditions:
i) High Gross Weight (GW) = 0.92 * MTOW
ii) Mid GW = Average of High GW and Low GW
iii) Low GW = [0.45 + 0.55*(MinW/MTOW)mean] * MTOW
where (MinW/MTOW)mean = $1.151*MTOW^{-0.0759}$

(Note the mildly disguised fact that all 3 points are simply manipulations of MTOW alone.)

• Links

The following are some examples of external sources that reference Piano in the context of environmental emissions. Note that none of these references are in any way connected to the views expressed in this letter. (All links retrieved in June 2012.)

"Guidance Material for the Development of States' Action Plans - Towards the Achievement of ICAO's Global Climate Change Goals" September 2011
http://www.icao.int/environmental-protection/Documents/GuidanceMaterial_DevelopmentActionPlans.pdf

"Department of Transport - UK Aviation Forecasts" August 2011
http://assets.dft.gov.uk/publications/uk-aviation-forecasts-2011/uk-aviation-forecasts.pdf

"CO2 Emission Metrics for Commercial Aircraft Certification: A National Airspace System Perspective" March 2012
http://web.mit.edu/aeroastro/partner/reports/proj30/proj30ato.pdf

"Future Aircraft Fuel Efficiencies - Final Report, QinetiQ" March 2010
http://assets.dft.gov.uk/publications/uk-aviation-forecasts-2011/future-aircraft-fuel-efficiency.pdf

"Study on the Allocation of Emissions from International Aviation to the UK Inventory Final Report to DEFRA Global Atmosphere Division - Allocation of International Aviation Emissions from Scheduled Air Traffic – Present day and Historical" December 2005
http://www.cate.mmu.ac.uk/documents/projects/mmuallocationsreport2currentdayv1_5.pdf

"Study on the Allocation of Emissions from International Aviation to the UK Inventory Final Report to DEFRA Global Atmosphere Division - Allocation of International Aviation Emissions from Scheduled Air Traffic – Future Cases, 2005 to 2050" March 2006
http://randd.defra.gov.uk/Document.aspx?Document=GA01060_3754_FRP.pdf

"Use of Third-party Aircraft Performance Tools in the Development of AEDT" July 2011
http://ntl.bts.gov/lib/39000/39700/39745/DOT-VNTSC-FAA-11-08.pdf

"Efficiency Trends for New Commercial Jet Aircraft" ICCT November 2009
http://www.theicct.org/sites/default/files/publications/ICCT_Aircraft_Efficiency_final.pdf

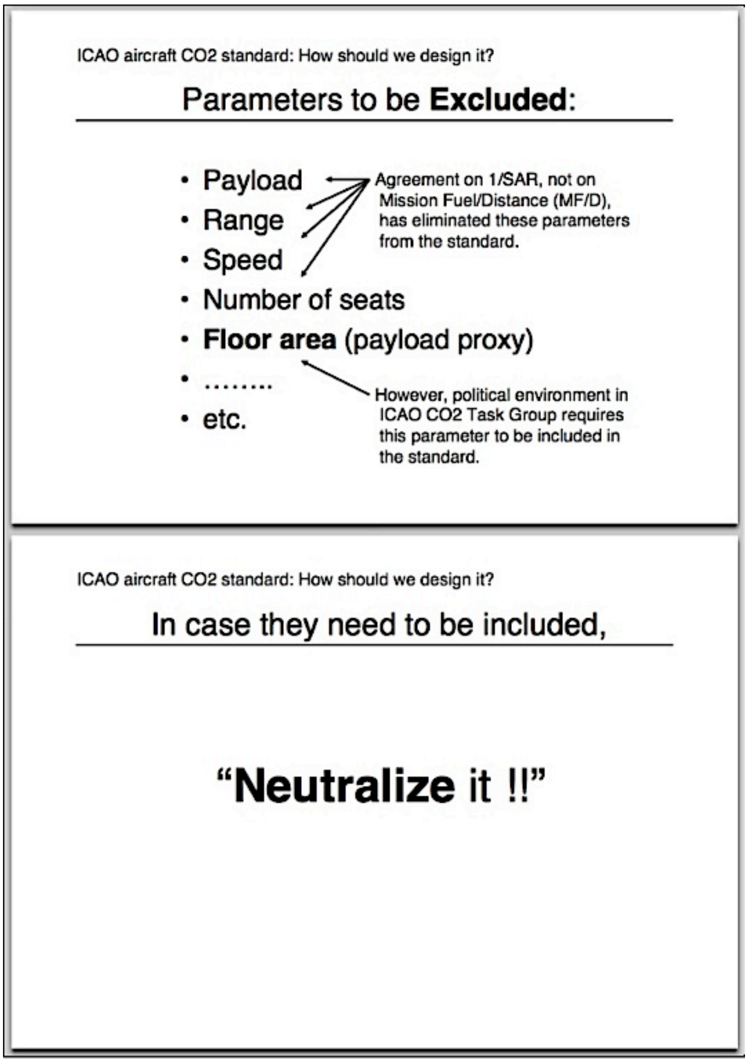
"Aviation Fuel Consumption Modelling" March 2011
http://www.volpe.dot.gov/coi/ees/acoustic/docs/2000/aviation_fuel_consumption_modeling.pdf

"AERO2k Global Aviation Emissions Inventories for 2002 and 2025" December 2004
http://aero-net.info/fileadmin/aeronet_files/links/documents/AERO2K_Global_Aviation_Emissions_Inventories_for_2002_and_2025.pdf

"Forecasts of CO2 emissions from civil aicraft for IPCC" November 2006
http://www.bis.gov.uk/files/file35675.pdf

"Aviation and the Global Atmosphere - 9.3" IPCC, 2001
http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/aviation/134.htm

Addendum: Perspectives of one manufacturer participating in the ICAO process



'When in doubt, tell the truth' - Mark Twain