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Why do planes not fly the shortest routes? A review

Frédéric Dobruszkes

Université libre de Bruxelles (ULB), Faculty of Sciences, DGES-IGEAT, Av. F. D. Roosevelt 50, box 130/03, 1050, Brussels, Belgium

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ABSTRACT

Scholars and experts in air transport generally assume the distance flown between airports is the shortest route (also known as the great-circle distance or the orthodromic route). However, in the real world, planes follow longer itineraries. This paper reviews the factors of detours, based on interviews with pilots and experts in air navigation. Factors relate to (1) technical constraints, (2) natural processes (including meteorological conditions) and obstacles, (3) geopolitical factors and (4) social factors, which are all explored in this paper. Their temporary vs. permanent and spatial impact (small vs. long detours) varies significantly among factors and among cases, as well as their avoidable nature. Appropriate policies could lower detours. In addition, these results echo academic debates on the meaning of distance.

1. Introduction

Distances flown by commercial planes are a key indicator commonly used to rank airlines based on seat-km offered or on passenger-km carried, to feed interaction models (such as gravity models), to sort air traffic by distance classes or to compute fuel burnt and emissions of greenhouse gases and pollutants (e.g., Adey, Budd, & Hubbard, 2007; Duval, 2013). Most scholars, aviation experts and international organisations have assumed that planes follow the shortest route, also known as great-circle distance or the orthodromic route. This is possibly because most datasets and online aircraft trackers give only great-circle distances but not actual distance flown.

However, in the real world, virtually no flights follow the shortest route and, very strangely, this has been largely neglected by air transport geographers. In most publications involving distance flown, neither the factors nor the magnitude of detours are discussed. Actually, one needs to go far back – to the emergence of commercial aviation – to find discussions on factors that shape routes (see Beaumont, 1943; Parker Van Zandt, 1944). Since then, only some authors (Dacharry, 1981; Sealy, 1966) have tackled this issue, and recent books on air transport geography (Bowen, 2010; Goetz and Budd, 2014) have neglected it. Navigation manuals also give some indications (e.g., U.S. Air Force, 2005) of interest in factors related to detours. All in all, these authors have highlighted a restricted set of factors related to natural constraints (physical geography and weather), technical limits related to aircraft ranges and some geopolitical concerns. As stated by Mason (1936), *"The extension of air-routes throughout the world has been mainly due to private enterprise and individual daring. But such enterprise can only be fully effective if all countries are sympathetic to intercourse by air. When therefore we see on such a map the lack of modern communications across the northern frontiers of India, we have to take into consideration the political factor as well as the physical barrier."* However, as far as I know, no one has pursued an exhaustive review of the factors involved in detours.

In this context, the aim of this paper is to unveil the extensive range of factors that impose detours on commercial flights. To do so, a twofold strategy was pursued. The first step was to scrutinise publications (academic, then not academic). It was found that most of these factors actually focus on technological matters (e.g., Tooley & Wyatt, 2018) or on the characterisation of air navigation route networks (e.g., Ren & Li, 2018; Sun, Wandelt, & Linke, 2015), but they do not focus on the very factors that force planes to follow given routes. As stated above, some of these factors can nevertheless be found in older books and in navigation manuals. Second, two experts in air navigation (one air navigation service provider and one consultant) and two pilots were interviewed. One pilot flies short- and medium-haul flights on Boeing narrow-body jets; the other flies medium- and long-haul flights on Airbus wide-body jet). Since publications are scarce, the interviews contributed to the largest part of this paper. In addition, several radar traces were retrieved from the Flightradar[1] website to illustrate concrete deviations and to compute related distances flown.

Before reviewing factors of detours, Section 2 recalls the key concepts needed to avoid the pitfalls of cartographic projections for mapping air routes. Section 3 reviews the factors of detours. Section 4 discusses the results and concludes.

E-mail address: frederic.dobruszkes@ulb.ac.be.

[1] See www.flightradar24.com/. Technically speaking, Flightradar subscribers can export selected radar traces to KML files that can then be imported into a GIS and superimposed on other layers.

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2. Projection, great-circle distances and mapping issues

Appropriate cartographic projections in the air age are a classical issue that was discussed a long time ago (Moore-Brabazon, 1944; Parker Van Zandt, 1944; Sealy, 1966; Stewart, 1943). Subsequently, air transport geographers have tended to neglect cartographic issues, despite the fact that inappropriate choices lead to misrepresentations. Let us recall that flattening the earth to produce a flat map with as much spatial continuity as possible involves stretching or shrinking the surface area unevenly, and this inevitably alters shapes, distances, directions and possibly broad spaces, which can present a problem, subject to projections and especially when "large" portions of the earth are mapped (Robinson, 1988). It is important to keep in mind that because distances are usually distorted, they are simply false compared to the reference globe, except along specific lines. Subject to the projection, these lines can be the Equator, certain or all meridians, some or all parallels, or all lines from one specific point. This means that with small-scale projections, the scale is not constant and is thus true only along some specific lines.

All this makes mapping the shortest routes, compared to actual routes flown, everything but neutral. One needs to guarantee that the reader will interpret distances on the map properly. In the real world and considering "long" routes, the shortest route between two points is a curve (Fig. 1), which is a great-circle arc.[2] The shortest route between two points, therefore, is often called the great-circle route, and the related distance is often referred to as the great-circle distance. In most cases, flattening a curved great-circle arc can only result in a complex curve on the map. In most projections, the shortest routes are thus anything but straight lines (Fig. 2).

All azimuthal projections have the advantage that all great circles passing through their centre (which can be freely set) are straight lines on the map, because all directions from their centre are correct (Robinson, 1986). Among these projections, the azimuthal equidistant projection has the merit that any great circle passing through its centre will appear as a straight line on the map with the correct direction *and* distance. Distances will be correct along the line, and the whole earth will be visible (in contrast with other equidistant projections, such as the gnomonic projection), although areas are not maintained and shapes are highly distorted at the edges (Gilmartin, 1991) (Fig. 3).

It is thus not surprising early scholars interested in airline networks adopted the azimuthal equidistant projection (see Parker Van Zandt, 1944; Sealy, 1966), which was later confirmed by Snyder (1987), who only cites this projection for mapping global airline networks. As a result, most of the following maps will consider this projection, with the airport of departure or arrival as the centre. The gnomonic projection, in which any straight line represents a great-circle arc, will also be used in some cases that cover only restricted spaces (given the large distortions and the projection's restriction to areas significantly smaller than a hemisphere).

3. Why not fly the shortest route?

3.1. Technical factors

3.1.1. Air navigation network

Firstly, planes do not fly the shortest pathway because they follow airways designed and published by the relevant authorities. These airways are made up of line segments between beacons or waypoints that form a global air navigation network. This requires planes to fly from point to point more or less along these segments, so the pathways are broken lines instead of complex curves. Of course, the density of airways shapes the magnitude of detours, all other things being equal. Denser air navigation networks mean a higher probability of getting a straighter route between two airports. Fig. 4, which compares a sample of routes from Brussels, Belgium, and from Xi'an Xianyang, China, illustrates this. From Brussels, the dense European air navigation network makes routes rather smooth. From Xi'an Xianyang, the relative shortage of airways involves complex routes that are far from being straight lines, as Ren and Li (2018) found. This is due to the fact that in China, 80% of the airspace is devoted to military uses (Hsu, 2014).

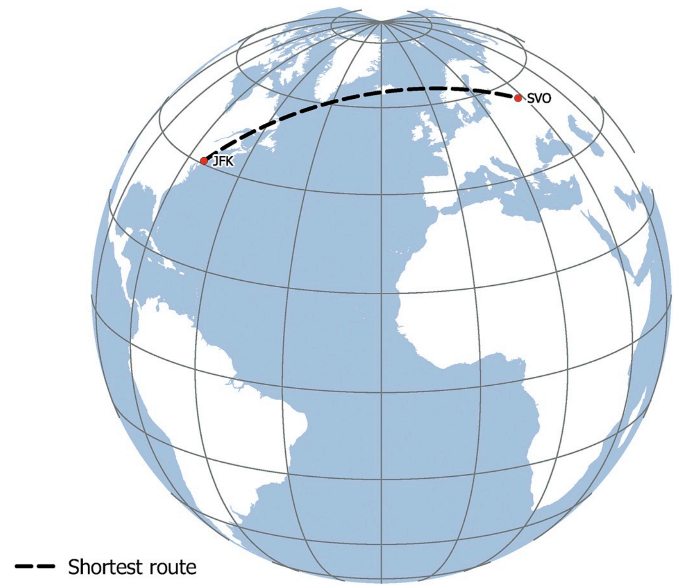

Fig. 1. The shortest New York-Moscow route on an orthographic projection.

Note that subject to various factors (including traffic density), pilots may receive a shortcut, so some intermediate points may be bypassed and the pathway shortened to some extent. In addition to en-route charts, procedures for take-offs and landings also impose detours, which are due to technical constraints, environmental concerns (noise exposure) and the complexity of the airspace, especially when airports are close to each other or affected by borders.

3.1.2. Traffic density and airport congestion

In the case of high-density en-route traffic, the capacity of existing routes can be insufficient. In such cases, one option is to (re)route planes via alternative airways, which means longer journeys. In addition, flights may be affected by congestion at and around the arrival airport. Given the minimal time/distance between two landings, it could be that planes are forced to engage a so-called holding pattern procedure, which involves following a racetrack-like ('stack') pattern until the way is clear for landing. For shorter flights, the resulting extra distance flown is proportionally higher compared to the normal route.

3.1.3. Time to alternate airports and extended operations (ETOPS)

Since the early days of aviation, the possibility of a technical failure has meant planes should not move too far away from alternate airports,[3] so they have an option to land before reaching their normal destination. Back in the 1950s, the first regulations were quite restrictive in this regard, considering the (lack of) reliability of piston engines used at the time (Taylor, 1990). Both the ICAO and the US Federal Aviation Administration (FAA) adopted regulations based on flying time to suitable alternate airports. The ICAO adopted the so-called '90-min rules' for twinjet operations, based on all-engine cruising speed. On its own, the FAA imposed a 60-min rule for two- or three-

[2] For those not familiar with geography, a great circle is a line that divides the earth into two hemispheres. The equator and any meridian are specific examples of great circles; all other great circles are oblique.

[3] Including certain military airports.

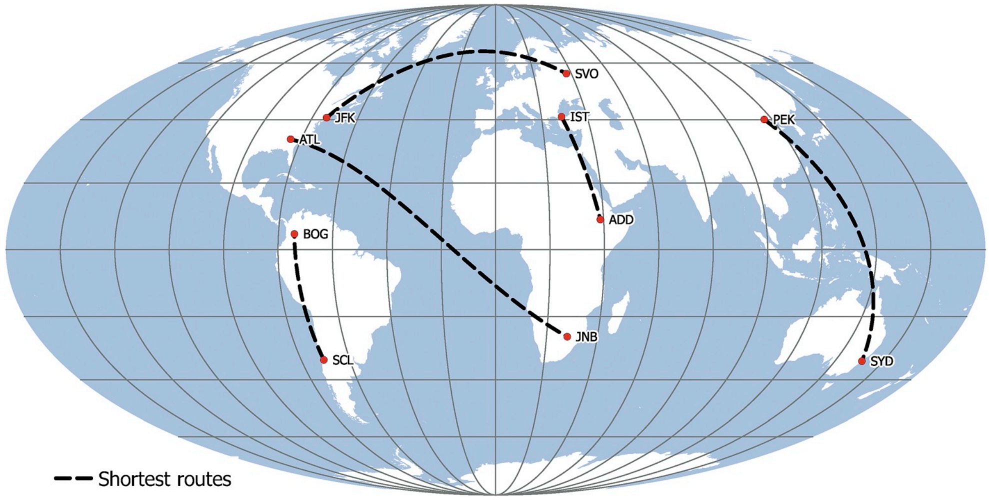

Fig. 2. The shortest routes on a Mollweide projection. Areas are maintained, but directions, distances and shapes are not.

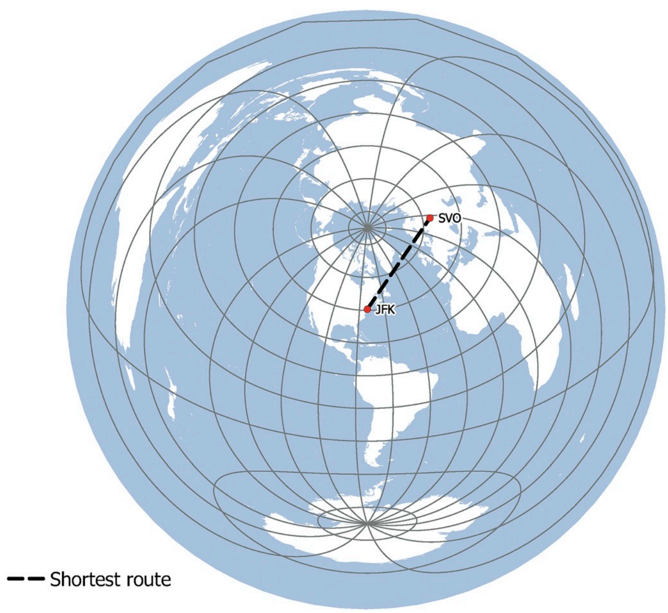

Fig. 3. The shortest New York-Moscow route on an azimuthal equidistant projection centred on New York.

engine planes based on cruising speed with one engine not working.[4] Hence, the strategic nature of remote islands under the sovereignty of so-called developed countries, such as the United States, which has its Minor Outlying Islands (e.g., Wake Island Airfield and Midway Atoll's Henderson Field) serving trans-Pacific flights, or the British Overseas Territories (e.g., the Ascension Island Auxiliary Field, which serves operations via the South Atlantic) (see Jones & Mehnert, 1940; Spoehr, 1946). Then, in the 1960s, three-engine planes were exempted. These rules contributed to the success of three- and four-engine planes used for long-haul operations, especially over the oceans (Lin & Lin, 2010).

More reliable engines then made it possible to think about so-called ‘extended-range twin-engine operation’ (ETOPS). Initial ETOPS certifications were designed based on a diversion time of 90 min. From 1985, initial rules were thus progressively relaxed as long as manufacturers, airlines, crews and dispatch staff met the various conditions of each ETOPS certification (see Chiles, 2007; Lin & Lin, 2010). So came ETOPS for 120 (e.g., A300 and B737 Classic), 180 (e.g., A320 family, B737s NG, B757s, B767s), 240 (e.g., A330s), 330 (e.g., B777s and B787s) and even 370 min (A350). Certifications can evolve over time and either increase (for instance, B777s and B787s have moved from ETOPS 180 to ETOPS 330) or decrease subject to technical failures. And about ten year ago, the ETOPS acronym was refined into ‘extended operations’ by the FAA and subsequently other authorities, so all commercial multi-engine aircraft are now affected (Chiles, 2007). Out of operations under the ETOPS umbrella, FAA's standard diversion time has remained 60 min for twinjets, and has become 180 min for planes with three engines or more.

With such progress, there are fewer lands with no alternate airports. However, flying long distances over the oceans can still force airlines to fly away from the shortest routes to stay within appropriate distances to alternate airports. It is common to introduce ETOPS navigation with circles around airports of departure as well as alternate and final airports. Notwithstanding the frequent misuse of map projections,[5] the reality is more complex than circles because one needs to take weather and air streams into account. Furthermore, various conditions may make existing “nearby” en-route airports inappropriate for diversion. Runway length, opening times and available rescue and fire-fighting services are key factors to be considered. Airlines may also favour diverting airports that enable aircraft to avoid unfriendly countries or have appropriate technical support (so aircraft are not grounded for unnecessarily long periods).

Assessing the impact of ETOPS is not easy, since exact routes over the oceans are often not available from public websites such as Flightradar because of poor coverage in these areas. Fig. 5 shows an attempt to compare routes followed across the South Atlantic by a B767-300 and an A330-200. The former is expected to fly under ETOPS 180 specs. It could consider the RAF Ascension Island Auxiliary Field as an alternate airport, but the runway needs to be restored. As a result, the flight goes more north than expected, presumably to keep 3 h away from the West African coast. In comparison, the flights operated by an A330 (possibly under ETOPS 240 specs) have a much larger part of their route unknown, so the magnitude of the detour compared to the shortest route cannot be estimated. However, the fact the plane is not detected, like the B767-operated flight, suggests it follows a much more southern route, far from the South Atlantic's islands, which are equipped with aircraft signal receivers that feed Flightradar.

[4] The only exception reported was a 75-min deviation time given to two airlines (in 1977 and 1980) for flights between the US and the Caribbean (Taylor, 1990).

[5] Circles would be correct only in the case of a projection that is equidistant in all directions around each airport considered (departing, diversion and arrival airports).

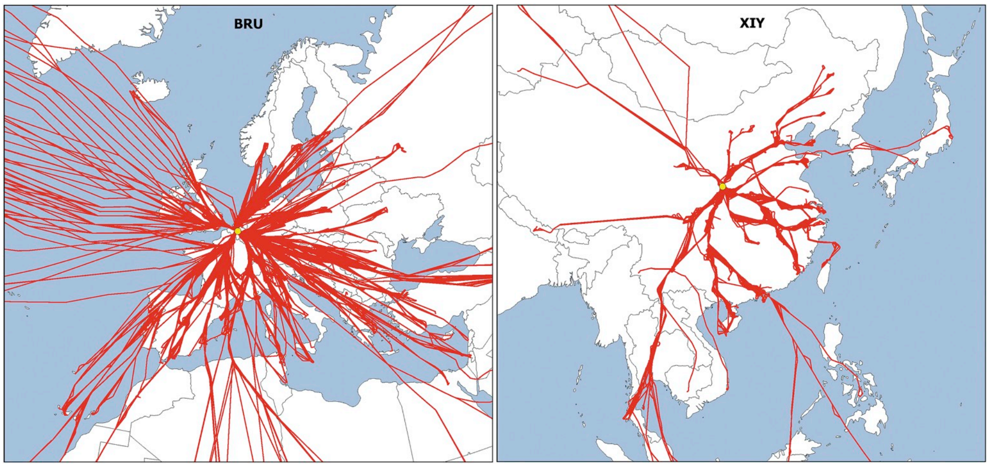

Fig. 4. The impact of air navigation networks on trajectories: flights from Brussels, Belgium (left, n = 1709) and from Xi'an Xianyang, China (right, n = 1480), November 3–9, 2017.
Source: Flightradar. Treatments and mapping: the authors.
Azimuthal equidistant projection centred on Brussels and Xi'an Xianyang.

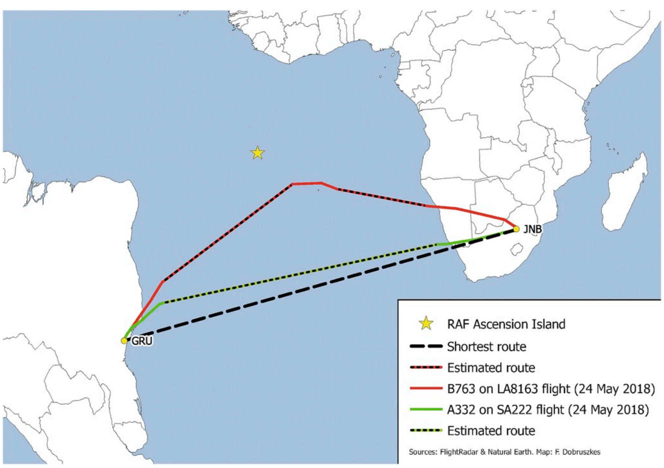

Fig. 5. Extended-range operations vs. aircraft type between Johannesburg (JNB) and Sao Paulo (GRU). The azimuthal equidistant projection is centred on Johannesburg.

3.2. *Natural factors*

3.2.1. *Relief*

Relief is likely the most evident physical barrier planes must avoid. Local obstacles are critical during landing and take-off, and usually require some detours. In addition, the largest/highest mountains impose detours if they induce disturbances above peaks or jeopardize the vertical separation of planes (see FAA, 1999). An extreme case is the Himalaya, which aircraft usually avoid, and thus have to fly significant detours. An example is given by Fig. 6. This is due to several causes, including strong air turbulence and disturbances as well as the need to descend to lower altitudes should an engine be lost or the aircraft loses cabin pressure, in which case it is not possible to descend over the Himalaya range.

3.2.2. *Jet streams*

Jet streams are the main air currents that affect air navigation. Indeed, their altitude (about 9–12 km for the polar jets streams and 10–16 km for the subtropical ones), their latitude, width (hundreds of kilometres) and intensity do interfere with flights. There are two jet streams per hemisphere. They all flow eastbound and their location changes over time, both on a seasonal basis and in the shorter term. This phenomenon explains why long-distance flights take usually more time toward the west than toward the east. As far as they can, planes fly eastbound in a jet stream and avoid it if they are westbound. It was thus recently reported that a B787 could fly from New York's JFK to London's Gatwick Airport in a record time of only 5 h 13 min, thanks to strong tailwinds that reached up to 325 kph.[6] And to cite one example, Tokyo-Los Angeles flights are about 1.5 h faster than the opposite way. Fig. 7 shows how much the deviation from the shortest route can be significant (in this case, it was to avoid a jet stream).[7] Of course, there is a trade off between the magnitude of the detour and savings. But in any case, this is arguably the only case of a “positive” detour in terms of costs, fuel burnt and emissions.

3.2.3. *Weather: thunderstorms and cyclones*

Thunderstorms and associated cumulonimbus clouds are dangerous for air navigation, and planes usually avoid them. Risks occur near ground level and en route since cumulonimbus clouds can reach altitudes far above usual flying altitudes. Associated adverse risks include stalling near ground level following a wind shift, torrential rains and hail that could damage the aircraft, updraughts and downdraughts, turbulence and tornadoes that could induce a loss of control, high-level ice-crystal icing that could cause engine damage, perturbation of on-board measuring devices, etc.

As a result, in most cases, avoiding thunderstorms is highly recommended by increasing altitude or skirting the storms. The detour depends on the vertical and horizontal extent of the cumulonimbus clouds and the fact that certain effects may occur for dozens of kilometres around them. The extent of cumulonimbus storms ranges from a few to hundreds of kilometres.

In the same vein, all kinds of cyclones induce torrential rains, thunderstorms and strong winds, while navigation aids may be disrupted by static electricity.

3.2.4. *Volcanism*

Aircraft must also avoid active volcanism. Indeed, volcanic ash is a serious threat as it can induce electrical failures (due to its electrostatic charge), cabin dust, abrasion damage, incorrect instrument readings, damage to the engines, and engine failure that requires in-flight restart

[6] Airliner World, March 2018.

[7] In other cases and subject to jet streams' location, the detour could be on an eastbound flight, and would thus be explained by the desire to be pushed by the current.

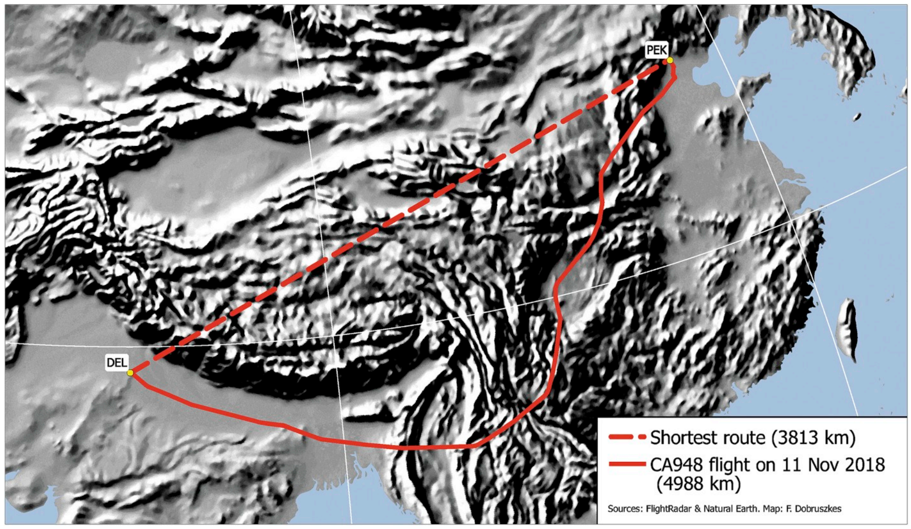

Fig. 6. Skirting around the Himalaya from Delhi to Beijing.Azimuthal equidistant projection centred on Delhi.

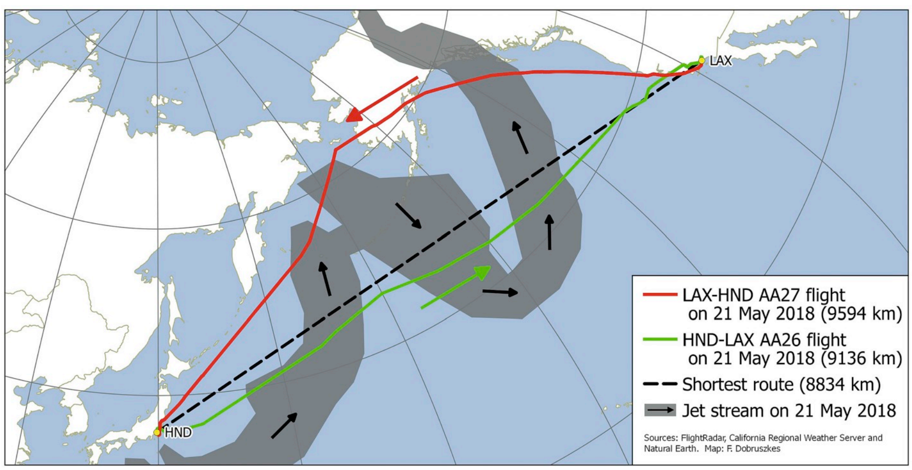

Fig. 7. The impact of a jet stream on the Tokyo-Los Angeles route. Azimuthal equidistant projection centred on Tokyo (HND).

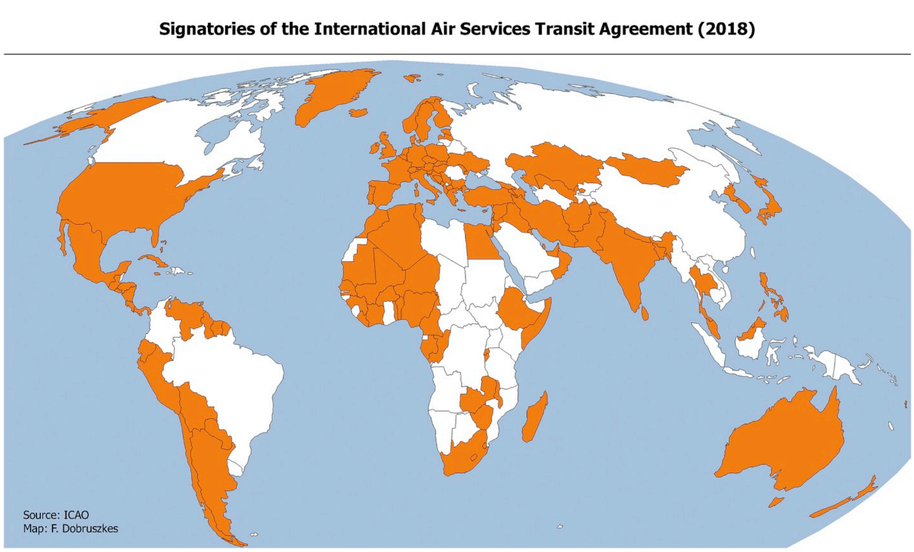

Fig. 8. Signatories to the transit agreement.

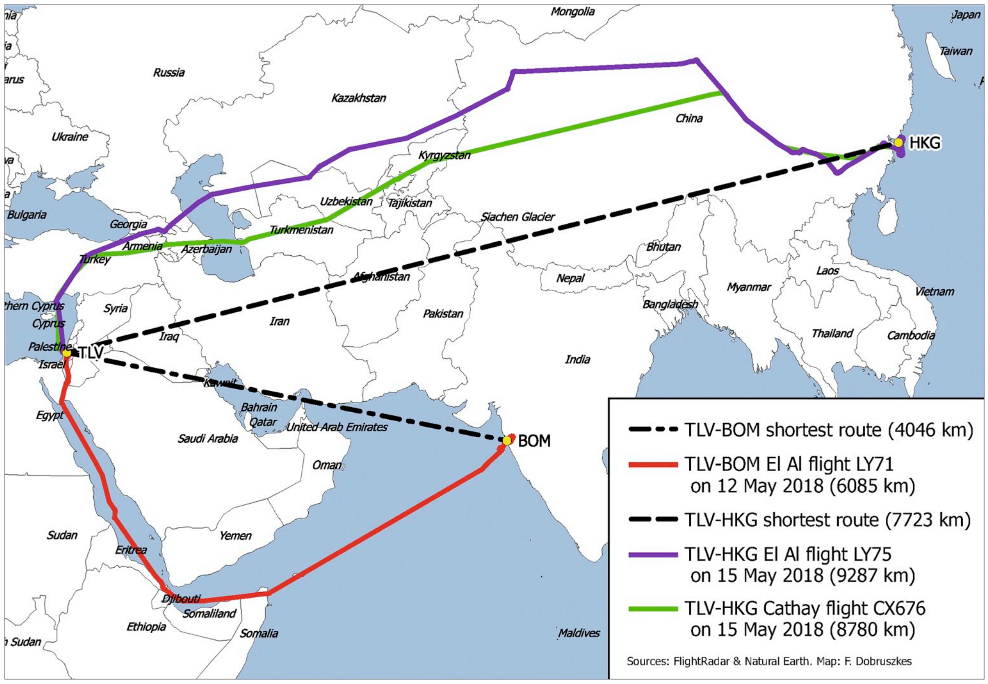

Fig. 9. The impact of no-overfly rights on routes from Tel Aviv.
Azimuthal equidistant projection centred on Tel Aviv.

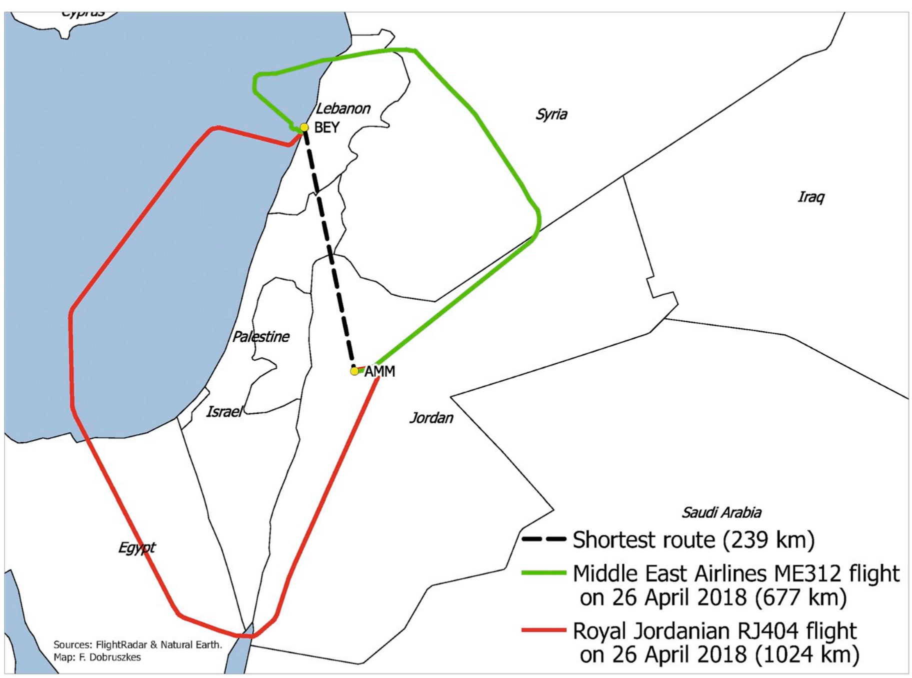

Fig. 10. Routes between Beirut and Amman Azimuthal equidistant projection centred on Beirut.

(see Casadevall, 1994; Alexander, 2013). In most cases, planes make reasonable detours to avoid such dangerous areas. But subject to the location and intensity of the eruptions, as well as ash dispersion patterns, detours may be longer or planes may be grounded. The most emblematic recent case is the 2010 Eyjafjallajökull eruption. While the eruptions occurred in Iceland, up to 75% of Europe's flights had to be cancelled and millions of travellers were stuck (Alexander, 2013).

3.3. *Geopolitical factors*

3.3.1. *First air freedom*

It is well known that the International Civil Aviation Conference held in Chicago in 1944 failed to adopt a multilateral liberal agreement. The extension of states' sovereignty over their sky was confirmed, so international air traffic needs to be allowed, and this has been achieved

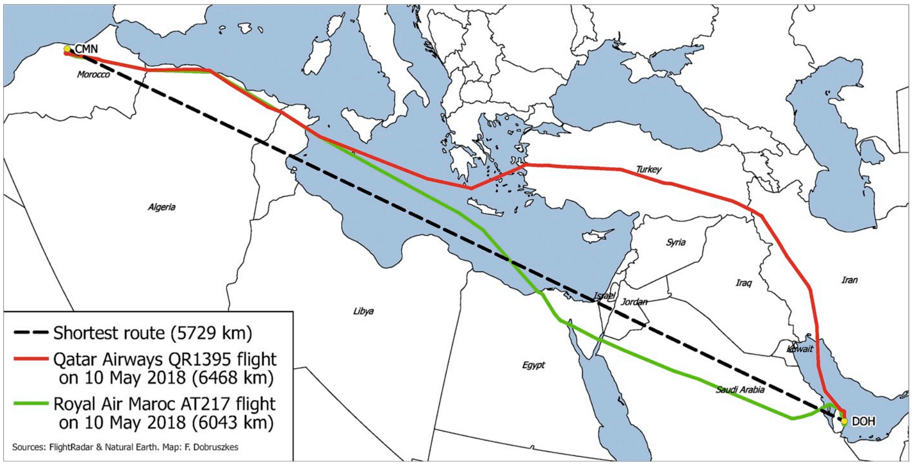

Fig. 11. Routes between Doha and Casablanca Azimuthal equidistant projection centred on Doha.

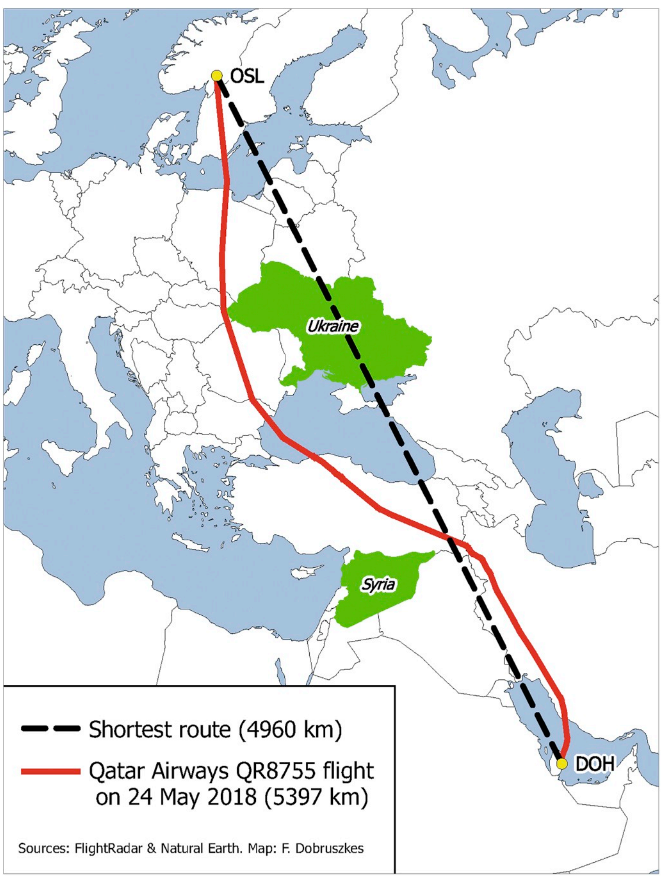

Fig. 12. Avoiding Ukraine and Syria between Oslo and Doha. Azimuthal equidistant projection centred on Doha.

mostly through bilateral agreements negotiated by country pairs. However, an International Air Services Transit Agreement – aka IASTA or the Transit Agreement – was signed in 1944, although by fewer countries. The Transit Agreement grants rights of overfly (first air freedom) and of technical stop (second air freedom) on a multilateral basis to all signatories. As of mid-2018, 133 parties (including some dependencies) had signed IASTA. As evidenced by Fig. 8, there are still vast areas that are not free for transit, including Canada, Brazil, Russia, China and roughly half of Africa.

For the rest, signatories may refuse the right of overfly to airlines registered in non-signatory states, and non-signatories can refuse any airline the right of overfly. As a result, drawing air routes has to be done under the constraints of overfly rights, which often reflect geopolitical patterns. For instance, Israeli airlines cannot fly over many Muslim countries, so significant detours appear on certain routes (Fig. 9). Interestingly, flights operated by non-Israeli airlines also skirt around the same countries. It is unclear whether this is a precaution or whether it suggests that exclusion may also be based on the flight origin or destination, in addition to the airlines' country of registration.

Of course, the opposite is true too, as evidenced by the very long detours (in proportion) visible on routes between Beirut (Lebanon) and Amman (Jordan) (Fig. 10). There is no doubt Lebanon-based airlines cannot fly over Israel. In contrast, Royal Jordanian commonly flies over Israel following the 1994 Israel-Jordan peace treaty. However, there are restrictions based on the origin or destination of the flight. Flights to/from Europe and the US are routed via Israel, but not flights from/to Lebanon. In this context, Fig. 10 shows that detours experienced diverge based on airlines' country of registration. Lebanon-registered Middle East Airlines goes via Syria, which is understandable given the proximity between President Bashar al-Assad and the Lebanese government through Hezbollah. Conversely, Royal Jordanian has to avoid Syria and Israel in this case, so the airline routes its planes via the Mediterranean and Egypt, which is a much longer detour.

Another significant case comes from the recent dispute between Saudi Arabia and Qatar. Before this dispute, Qatar Airways used to fly over Saudi Arabia. Today, however, the airline is banned over this country so it must consider large detours given the vast area of Saudi Arabia. In contrast, airlines registered in other countries and serving Qatar are still allowed to overfly Saudi Arabia. As a result, distance and time flown can significantly diverge on the same route, subject to the airline. Between Doha and Casablanca, for instance, Royal Air Maroc can fly a rather straight route via Saudi Arabia (avoiding Israel and Libya, though), while Qatar Airways has to skirt around it (Fig. 11). What is more, the detour is extended by the need to avoid Syria (see below). In the end, Qatar Airways' flight is 7% longer than Royal Air Maroc's one. This potentially involves anticompetitive consequences, all other things being equal.

3.3.2. War, terrorism and 'demonstrative' regimes

War, terrorism and the activism of 'demonstrative' regimes also make several areas too dangerous to be overflown. The risk of a plane being hit by a missile accidently in the context of training or a display of strength (such as those exhibited by North Korea) is arguably very low. However, planes can be targeted, intentionally or by mistake (as was the case with Malaysia Airlines Flight 17, shot down in 2014 by a surface-to-air missile at an altitude of more than 10 km over Ukraine). During landings and take-offs, it is rather easy to hit a plane with much

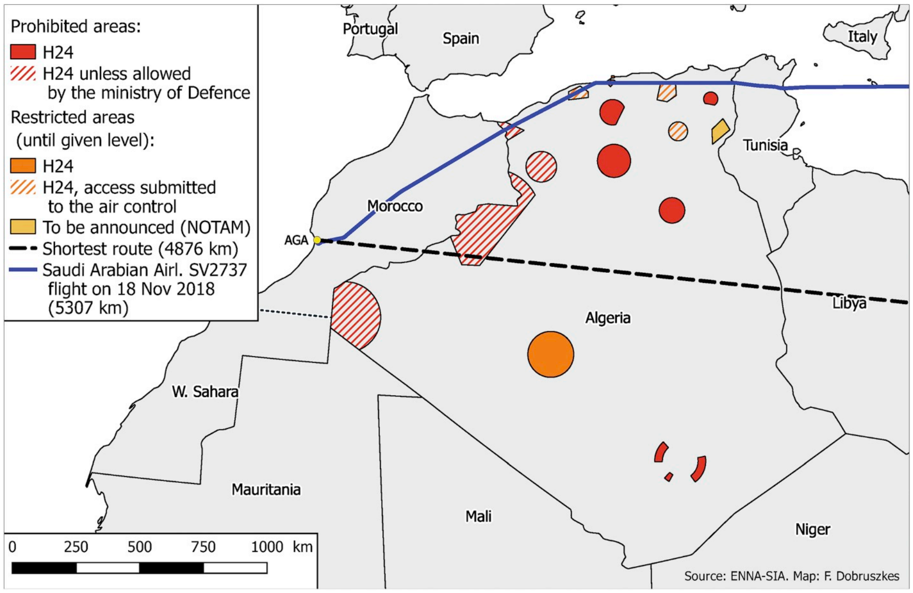

Fig. 13. Algeria's no-fly areas and their impact on the Agadir-Medina route. Gnomonic projection centred on Algeria. H24 means permanently (24/7). A NOTAM (Notice to Airmen) is a notice issued by an aviation authority with short-term information or instructions.

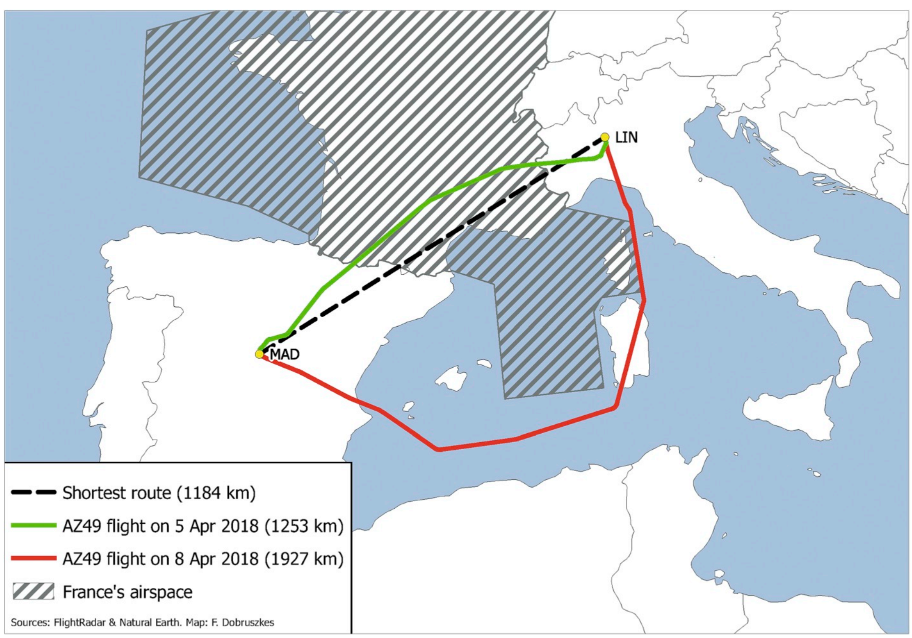

Fig. 14. The impact of France's airspace closure following a strike on the Madrid–Milan route. Azimuthal equidistant projection centred on Madrid.

lighter missiles that can be easily carried and launched. Rebels and other armed groups in various countries carry these weapons.

All this suggests that some areas should be avoided and indeed, there is a long list of exemples. At the time of writing, most international flights not serving Syria and Ukraine were avoiding them. Fig. 12 shows a very concrete case. From Oslo to Doha, the shortest route would be via Ukraine. Bypassing this country via the West, the shortest route for the remaining journey would cross Syria, which is also avoided. So, ultimately, two detours are imposed, which makes the resulting distance 8.8% longer. Similarly, recent tensions between India and Pakistan have involved the closure of Pakistan's airspace over several weeks and restrictions at several Indian airports, notably involving detours for en-route traffic. Also, recent troubles in Sudan have induced the temporary closure of its airspace.

3.3.3. No-fly areas

Finally, any state can define no-fly areas. Such areas can be permanent or temporary, and only to a specified altitude vs. an infinite one. Permanent bans usually cover electric plants, military facilities, spaces occupied by aerial training, space centres, city centres (e.g., the heart of Paris below 2000 m), and oil or gas extraction fields. Temporary bans may include summits with 'important' leaders and military parades. One should also distinguish prohibited areas (total ban) and restricted areas (where the ban can be lifted subject to approval by air control). In addition, bans and restrictions can apply to a given altitude only, while public air services or military operations can be exempted.

The size of these areas ranges from really small to much larger units. Considering Algeria, for instance, there are 11 prohibited areas and eight restricted areas (Fig. 13). These areas relate to military facilities

Table 1
Factors related to detours and the main attributes.

Nature	Factor	Temporality	Detour magnitude	Airlines affected	Impact on fuel burnt	Avoidable (airline perspective)	Avoidable (government perspective)
Technical	Route design	Permanent	Mixed	All	Increase	No	Yes (if extra airways can be added)
	Traffic density	Temporary or permanent	Mixed	All	Increase	No	Yes (if extra airways can be added)
	Time to alternate airports	Permanent	Mixed	Subject to each airline's fleet mix	Increase	No	No
Natural factors	Relief	Permanent	Mixed	All	Increase	No	No
	Storms	Temporary	Mixed	All	Increase	No	No
	Jet streams	Permanent but changing location	Large	All	Decrease (tail) or increase (front)	No	No
	Cyclones	Temporary	Small	All	Increase	No	No
	Volcanism	Temporary	Mixed	All	Increase	No	No
Geopolitical	First air freedom	Permanent	Mixed	Subject to airline's country of registration and to international relations	Increase	No	Yes, adopting a more open policy
	No-fly zones	Temporary or permanent	Mixed	All	Increase	No	Yes, relaxing non-crucial restrictions
	War, terrorism	Temporary (hopefully)	Mixed	All	Increase	No, but risking the life of passengers and crews	No
Social	Strike	Temporary	Mixed	All	Increase	No	Seeking to limit strikes by appropriate initiatives

and training spaces, one nuclear research centre, oil or gas extraction sites and undetermined sites. The military spaces also target the border with Morocco in the context of recurrent tensions between the two countries in relation to the status of Western Sahara and to mutual accusations about hosting terrorists and the drug trade, which have resulted in the surface border being closed since 1994. Prohibited and restricted areas are of various sizes; the largest prohibited one extends for about 400 km. Fig. 13 also shows their impact on a route between Morocco and Saudi Arabia, even though the detour is also explained by the need to avoid Libya.

3.4. Social factors

3.4.1. Strikes

Air controller strikes can temporarily mean less available capacity and or no capacity at all in the event of airspace closure. As a result, flights that were supposed to go via the affected airspaces would either have to be cancelled or rerouted so they skirt around these areas. Fig. 14 shows a concrete example of a detour imposed by a strike in France. The detour added no less than 54% (in kilometres) to the normal flight path.

4. Discussion and conclusions

In his pioneer work, Parker Van Zandt (1944: 7) highlighted "the myth of great circle flying". Three quarters of a century later, despite rapid technological progress and less global geopolitical concerns, flying the shortest routes remains somewhat hypothetical. A large set of factors involved in detours has been identified. These factors can be sorted by various criteria, including their very nature, temporality, spatial pattern, airlines affected (airline-specific factors vs. universal factors), impact on fuel burnt and thus on the environment, and whether the factors can be avoided (Table 1). According to a cost perspective, taking advantage of (or avoiding) jet streams is the only case of a "positive" detour that makes it possible to lower fuel burnt, and thus reduce costs, despite extra kilometres. Interestingly, airline route designers have to consider trade offs between various parameters. Designing and optimising airline routes is thus a very concrete case of an applied geography exercise, made up of constraints of all kinds, trade offs and thresholds.

Table 1 also shows that if most factors apply to all airlines, two of them – namely, time to alternate airports and first air freedom – are selective. Time to alternate airport is in the hands of the airlines to some extent, subject to their fleet mix. Airlines that have invested in aircraft certified for longer ETOPS can fly more direct routes, all other things being equal. In contrast, the first air freedom issue is out of airlines' control, because of diplomacy and international relations issues. All in all, these two factors can differentiate airlines in terms of competitiveness, considering that, in most cases, longer distances involve longer travel time and higher operating costs, and that passengers are sensitive to the magnitude of the detour[8] (Choi, Wang, Xia, & Zhang, 2019).

Finally, Table 1 suggests that several factors relating to detours could be avoided (or at least softened) should public authorities adopt relevant policies and strategies. While natural factors are, of course, given in the context of actual technologies, the design of air navigation networks, most geopolitical factors and social factors could be less burdensome than today, subject to policies. In other words, not all detours are necessarily a serious impediment.

In addition, this paper paves the way for further research. Firstly, the next logical step would be to assess how long the deviations are. Given the wide range of factors and the fact they may occur at various

[8] At least in the context of selecting indirect routes with various options of airport to transfer.

places and be of various sizes, such assessment will need to consider a large set of flights. In addition, the quantitative importance of each factor should also be investigated. This would likely be a complex task because of the effects of combined factors.

Finally, this paper echoes academic debates on the meaning of distance. Distance in all its forms (straight line distance, time distance, cognitive distance, etc.) is certainly a core dimension of geographical sciences (Gatrell, 1983; Pirie, 2009), a fact evidenced by Knox and Marston (2007) observation that, *"The importance of distance as a fundamental factor in determining real-world relationships is a central theme in geography",* even though its *"effects are not uniform"*. Distance is also key in transport geography, both as a means to segment analyses and as a fundamental factor that shapes interactions between places. As Rodrigue, Comtois, and Slack (2013) stated, distance is *"the most fundamental element of geography in general and transport geography in particular."* Beyond these statements, it has been argued that, in most cases, *"rather than being problematized, [distance] is taken as self-evident, albeit elastic to some extent"* and that *"instead of a frozen and abstract object detached from the experience of crossing it"*, distance should also be considered *"as relational, meaningful, social and political. Attention to distance is attention to the in-between"* (Handel, 2018). An interesting point with the issue of detours in commercial aviation is that it builds a bridge between traditional and revisited political perspectives on distance. In short, this paper is certainly about the traditional issue of actual (accurate) distance to be considered by scholars. And, incidentally, it shows that even in its basic physical form, distance is still worth investigating. But understanding the factors of detours also involves thinking about the in-between (geo)political factors that make distances flown longer than the shortest routes, and thus about the gap between travel time and physical distance.

All this poses questions about today's (air) transport geography. Various reviews or progress reports related to transport geography have barely explicitly considered it worthy of scrutiny (e.g., Goetz, 2006; Keeling, 2007; Schwanen, 2016, 2017 and 2018). Considering air transport geography only, recent reflections on key issues and research perspectives have also neglected the concept of distance (e.g., Ginieis, Sánchez-Rebull, & Campa-Planas, 2012; Oum & Zhang, 2001; Vowles, 2006). And, somewhat symptomatically, keywords such as "distance" and "range" are missing in the index of air transport geography reference books in recent times (Graham, 1995; Bowen, 2010; Goetz and Budd, 2014), even though the concept is actually considered throughout the whole opus.

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