ogy cannot solve, radical new technologies usually come to rescue. The jet engine is a case. It came just when it was needed, although it was patented 30 years before. These innovations tend to come out around the end of Kondratiev cycles. For us this corresponds to 1995 ± 10 years. In the case of aircraft, apart from the hypersonic already quoted, there are other designs in the experimental stage. To give an example, the *surface effect wing airplanes (WIGs)* flying two or three meters above water surface (WIG, Wing In Ground effect, Fig.6-4). They are really hovercrafts without aprons, air being trapped dynamically under the stubby wings. According to Russian sources, where some prototypes have been built (Fig.6-5), a 1400 tons payload airplane for intercontinental traffic is possible. Using LH_2 as fuel and a more sophisticated design, the payload could be as high as 2500 tons. The plant, however, has to take off and navigate over water. The introduction of *Maglevs* with appropriate characteristics make large *intercontinental hubs* on sea possible, where traffic can be concentrated like in seaports.

Maglevs can in many ways be considered as low-flying electric airplanes. Current development of Maglevs in Germany and Japan points to the possibility of running these trains at *mean* speeds of 600 km/h , i.e., equivalent to the mean speed of airplanes in intra-continental service. The problem of Maglevs is that they have to move in fairly straight lines to limit lateral acceleration, and this normally requires a lot of tunneling. For a Tokyo–Osaka train, tunnels would cover about 60% of the stretch.

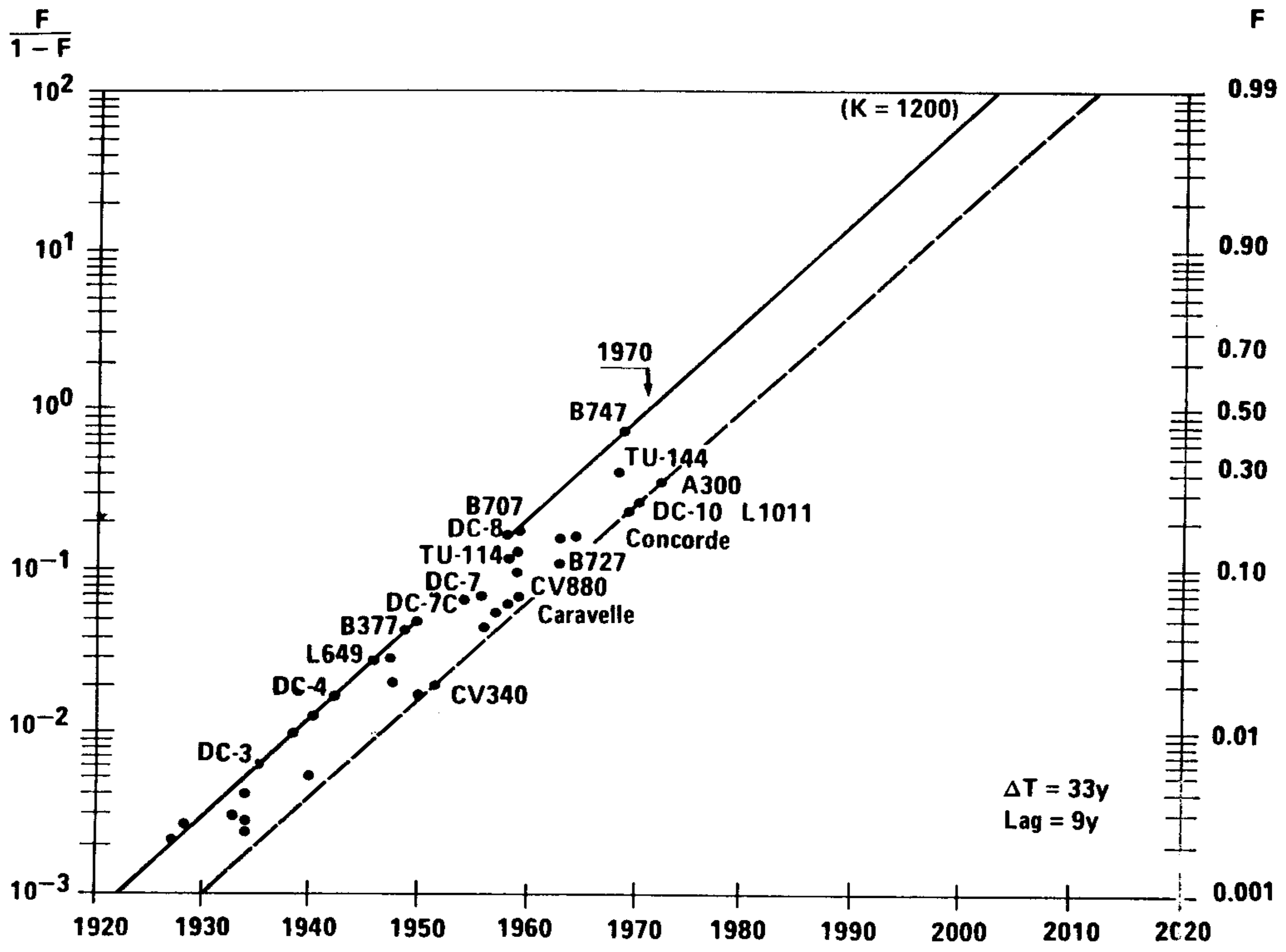
In a recent project by the Polytechnic Federal School of Lausanne, together with a number of Swiss industries, dubbed *Swissmetro*, this point was put to an advantage by making 100% of the stretch in a tunnel, *but with reduced air pressure* (15.000 meters equivalent). The reason for doing that is the reduction of the cross-section of the tunnel to that of the train, substantially reducing the amount of material extracted and consequently the cost of the tunneling. This cost is dominant and can be 80% or 90% of the whole cost of the infrastructure. The objective of *Swissmetro* is to connect couples of Swiss cities in about 10 minutes.

But if air pressure is reduced, then speed is not limited by air resistance, and we have proposed *Constant Acceleration Maglevs* (CAM) where the train is accelerated halfway and decelerated the other half, with acceleration values acceptable to the travelers. Even with relatively modest accelerations of 0.5 G (5m/sec^2) typical of sports cars (a new car by Audi, the *Avus* has an acceleration of 1 G) CAMs can simulate hypersonic airplanes even inside continental limits. To give an example, with 0.5 G a CAM could cover the distance of 500 km between Bonn and Berlin in about 10 minutes functionally fusing the two cities. Following the Swiss analysis, a three-tunnel train for that stretch would cost about 20 billion Marks. The system could have a passenger capacity of 100,000 people/h per direction. These Maglevs are certainly expensive but can be very useful where traffic density is too large for an air link. Like high-capacity glass fiber cables linking telephone exchange stations in a city, these trains could link high-intensity hubs, and in particular these devoted to intercontinental traffic, from which hypersonic airplanes and WIGs can pick up passengers and goods for the big jump.

Fig.6-1

Airplane productivity is defined as pass-km/h and is the product of airplane speed × capacity. It is a flux and can be compared with world air passenger traffic on the same units. This is done here for a number of specific machines, and it come out that the productivity of airplanes grows parallel to the traffic (dashed line). One of the consequences is that any increase in traffic can be dealt with using a constant number of airplanes of increasing productivity. This held true until about 1980, when a very fast growth pulse in pass-km developed and airplane makers were not ready to provide the right machine to cope with.

PASSENGER AIRCRAFT PERFORMANCE
(1000 Passenger — km/h)



N. Nakicenovic, 1986

Fig.6-2

The superjumbo that the system requires, following the past rule that the productivity of airplanes is proportional to traffic, has many problems. The most serious one is perhaps that of handling a large slug of people at deplaning, wittily adumbrated by the cartoonist of the *Economist.* In our conception of the airports, *all doors could be used* as mechanical stairs raise from the ground to funnel people straight into the underground where the Metro vehicles are located. These stairs should lie flat around the parking position of the plane and raise and twist to reach the doors.

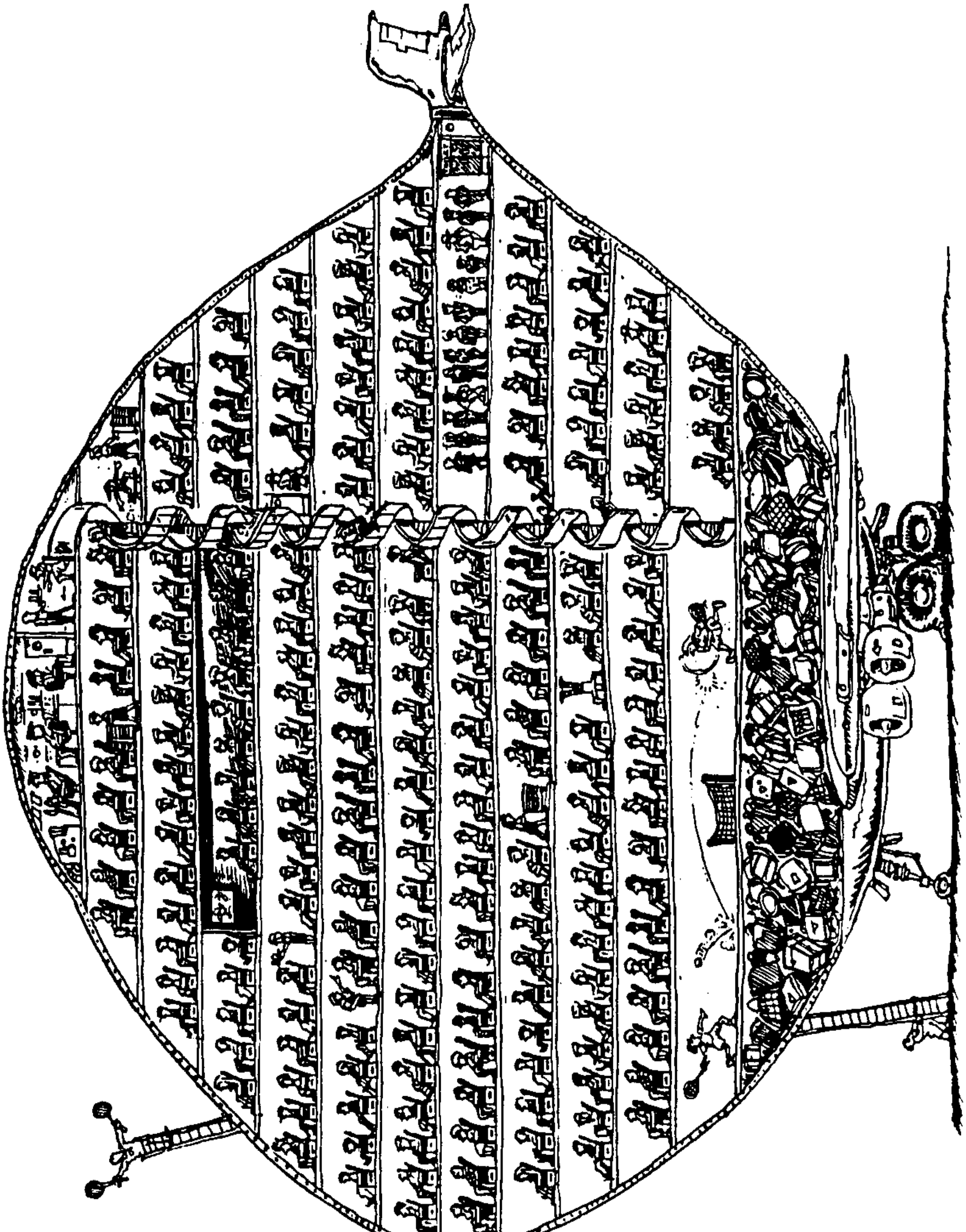


Fig.6-3

The problem with airplanes of increasing productivity is that they become larger and faster, requiring an increasing power from the engines. The situation is neatly described in this chart where the power (or the thrust) of the largest commercial engines is reported since 1905, and mapped using interpolating logistics. Piston engines were out of breath in the mid-Forties, the maximum power reached being about 4000 HP. At that time jet engines were introduced to provide the needed power. But at present also jet engines are out of breath, with thrust reaching 30.000 kg. More power could be obtained by inhaling more air through higher speed. Hypersonic planes seem on the cards, also for this reason.

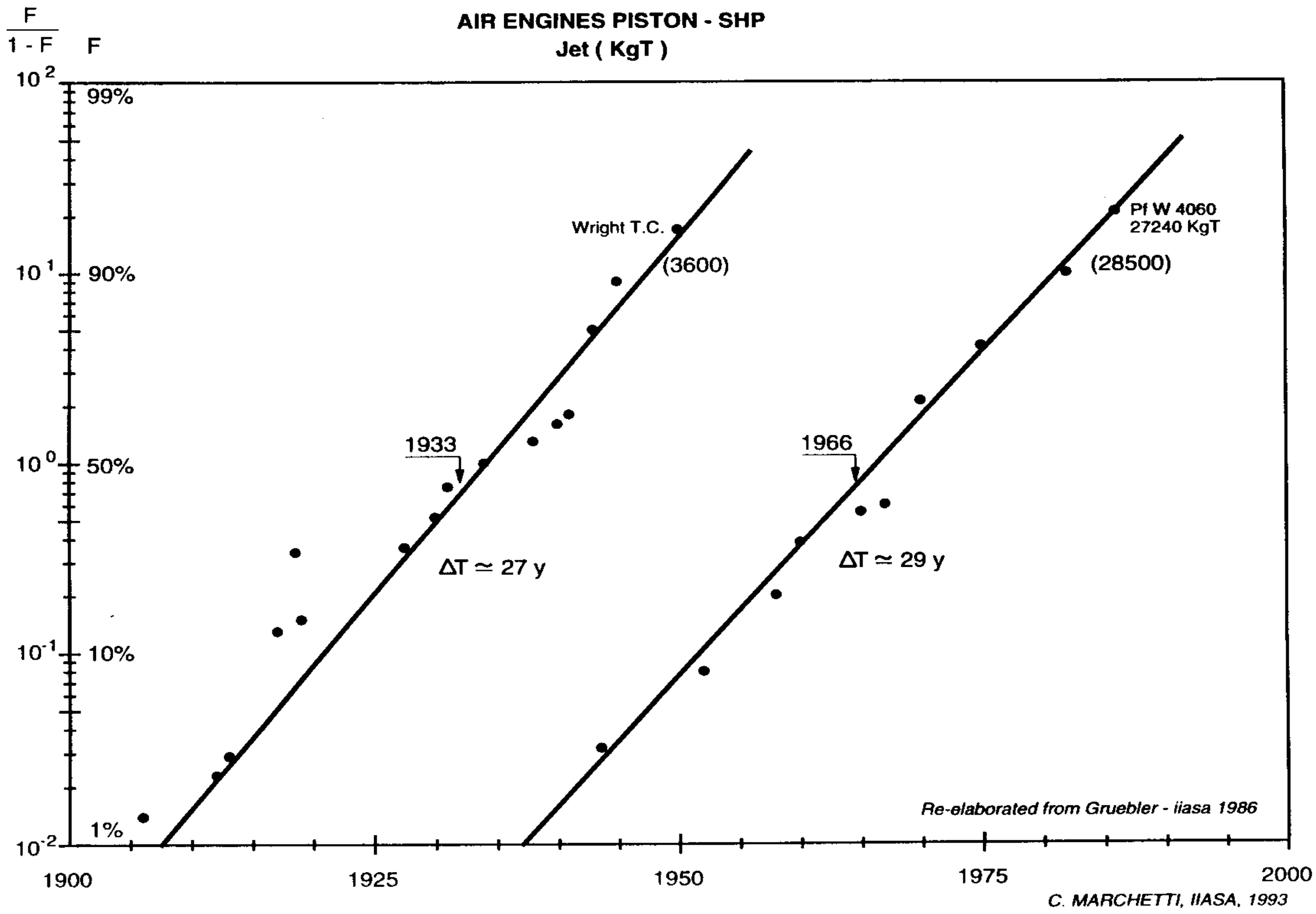


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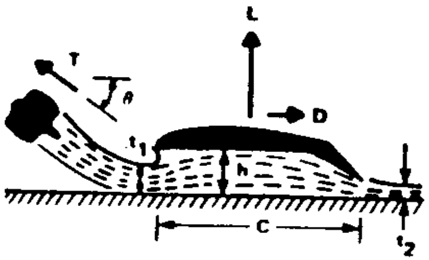
Fig.6-4

When problems become unsolvable with old technologies, usually a new one comes to rescue. For very high productivity planes the new concept of WIGs (Wing In Ground effect) opens new avenues. They are a kind of hovercraft where the bubble of air is kept dynamically under the wings and the body, without the necessity of an apron as explained in the sketches. WIGs have been under development for 30 years as military vehicles in Russia, and they are now redesigned for civil service.


T
L
D
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C
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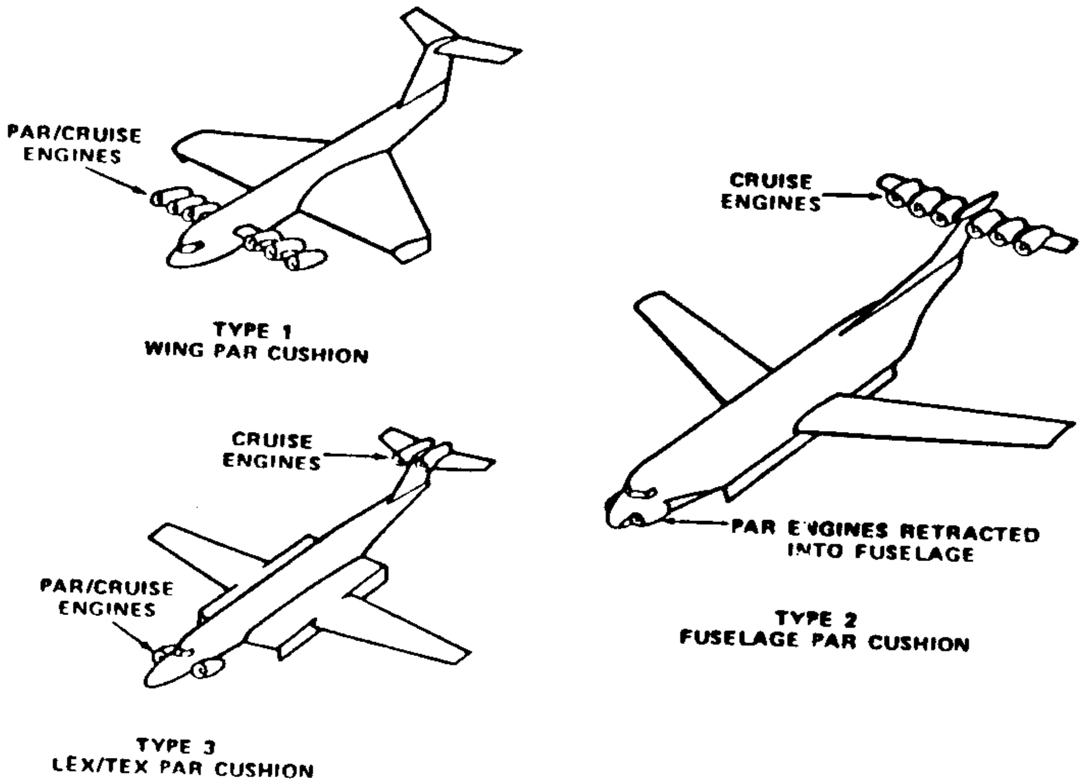
PAR/CRUISE ENGINES
TYPE 1
WING PAR CUSHION
CRUISE ENGINES
PAR ENGINES RETRACTED INTO FUSELAGE
TYPE 2
FUSELAGE PAR CUSHION
CRUISE ENGINES
PAR/CRUISE ENGINES
TYPE 3
LEX/TEX PAR CUSHION

Fig.6-5

According to most recent news, the WIG principle could increase by *an order of magnitude* the productivity of airplanes. 3000 tons of payload carried at speeds comparable to present jet speed, seem to be in reach. Russians built a large WIG experimenting it on the Black Sea, as the annexed spy photo shows. (Figure from *Aviation Week & Space Technology*, page 26, October 7, 1991; a new communication on WIGs for civil service can be found in AW&ST, page 62, April 26, 1993.)

Team Studies 2,000-Passenger Using Soviet Ground-Effect Technology

CRAIG COVAULT/WASHINGTON

A proprietary U. S. team of contractors is studying development of a 500-ft. transoceanic/wing-in-ground-effect (WIG) aircraft that could carry 2,000 passengers and 1,200 tons of cargo at 400 kt. The concept was pioneered by the 300-ft. Soviet "Caspian Sea Monster" shown here.

The U. S. WIG program could compete with future "super jumbo" air transports. The company leading the team—Aerocon, Inc., of Alexandria, Va.—has also received a $500,000 contract from the Defense Advanced Research Projects Agency to study military applications. The Caspian vehicle, which later crashed, is shown in the early 1970s with a ship docked to its wing (right).

In photos below, note the eight jet engines on the forward span and massive Y-tail. The seaplane was to have had an antisubmarine or antisubmarine-launched ballistic missile role. The Soviets currently operate a smaller 190 ft. "ekranoplane" derivative (AW&ST Oct. 7, 1991, p. 26). □

COURTESY ABC NEWS

7. On Airports: From Batch Operation to Continuous Flow

When the populace had a positive attitude toward technology and "progress", typically during the boom phase of the Kondratiev cycle, airports were the showpiece of local authorities' pride. As a consequence, airport terminals tend to be monumental, the dreams of the architect prevailing over the toils of the user. As a consumer of airports around the world I can safely state that no airport has ever been constructed with the passenger in mind. This is one of the reasons of the reigning chaos, and if we assume an order of magnitude increase in traffic due to come before 2020 *airport structures and passenger flow have to be rethought from first principles.*

Now what should an airport do? Basically bring planes in and out of the airport, and bring passengers in and out of the planes. This is the internal face. The external one is to bring passengers in and out their means of transport that diffuse them into, or concentrates from the hinterland and the city that usually sits nearby. In terms of chemical engineering, the processing of passengers in an airport today can be defined as a *batch operation.* People are shuttled from one container to the next, with some filtering here and there. Looking at them with the cynical eye of the systems analyst, the procedure appears nonsensical, at least from the point of view of the traveler. As every chemical engineer knows, passing from batch operation to *continuous operation*, one can increase the flow perhaps by 100 times with the same volume of plant. *Maybe chemical engineers should plan airports*, before the architect puts his hands on the stuff. In the chemical engineer's view, the *passenger should never stop between the chair at his desk and the seat on the plane.*

Let us try to visualize a possible configuration approaching such an ideal, and let us start from the internal side of the process:

- The tarmac where the planes are parked could be a big circle from which runways radiate out much like Kennedy airport in New York. One can obviously have one runway only.

- Under the tarmac there is a circular, *extended subway station*, with mechanical stairs rising to the level of the tarmac in the positions where the planes are parked.

- Reservations are done by phone, as in most cases today in the USA, and the ticketing process should be in the plane, as often in shuttles. Reservation tags should, however, be carried by the traveler. Because most travelers are habitual, and most people have credit cards, a special travel card should carry the necessary identification codes of the traveler. A vendor machine on the subway trains or at the airport gate can then interrogate the computer and deliver the tags.

- People suffer in parting from their luggage and luggage should be carried in the cabin (all stairs are mechanical) to be stored in special racks. Complimentary baggage handling could come in parallel, but the traveler gets his baggage under the plane when disembarking. Incidentally, this is the way baggage is handled on trains and buses.

- People disembarking have usually three destinations: city, parking lots, taxis (plus connecting planes). Trains in the circular station may stop at any bay if requested by pushing one of the corresponding three buttons. If these trains were Maglevs, as experimented in some airports, they could side-step for stopping, with one lane left for trains to move continuously. People moving to connecting planes can put their travel card into a slot and have commuter wagons shifting them to the proper bay.

- People embarking put their travel card in a slot in the wagon they come with. Their gate is identified, and the train stops there. The wagon can come from the city, from the parking lot, or from the taxis, all trains circle in rounds under the tarmac. Security checks can be made at the entrance stairs leading to the planes upstairs.

This configuration would transform an airport into a subway station, where airplanes can be visualized as connecting lines. The monumental buildings will have no functions any more, but they could be profitably recycled as *souks*, with shops, restaurants, Turkish baths, and convention centers.

Reconstructing the pathway of the *outgoing passenger*, he makes his reservations by telephone, then takes a subway line to the airport. This line can come from the city, taxi, or parking lot. Slotting his travel card he will be stopped at his flight's gate. Slotting again he will get the embarkation card and pass to move into the airplane. When seated he will pay the fare if not done otherwise.

Reconstructing the pathway of the *incoming passenger*, he will disembark into the platform of the circle, together with his luggage. If changing plane, he will slot and embark a circling vehicle that will land him at his flight's gate. If moving out he will push one of the three buttons, city, parkings, taxis, and the incoming train will land him at one of these places.

It all looks chemical engineering with computer control and no batching (trains come in minutes). People arriving too early may certainly clog the gates before the plane is ready to embark. But the *souk* will absorb any time and any money available. Most airports appear to sit in two opposite states, frantic or cavernous and empty. It seems that forecasting traffic and the necessary capacity has found no connection with the actual construction based more on pride and money available. But even elaborate (and contested) planning like the one that went into the Munich airport, did not bring much result. The capacity for vehicles and passenger handling was almost saturated the same day the airport was opened. In fact, delays due to "traffic" are as common now in Munich-2 as they were in Munich-1 (Fig7-1, Fig.7-2). The point we want to make after having analyzed a number of airports, is that logistic analysis provides a reasonable tool to forecast traffic although we could not forecast the start of a new wave inside the same Kondratiev. In this specific case the error, 15 years ahead, would have been macroscopic because the second fast wave has about the same value of saturation than the first slow one. We should develop a warning method for these second waves, perhaps through the taxonomy of the first one (e.g., saturation before the end of the Kondratiev).

Airports are infrastructures built to "fill" territories through connecting lines. As it happens with cities, or banks (or airplane capacity), the rank size description of the connections should correspond to a fractal distribution. Apart from descriptive elegance, these charts reveal disequilibrium situations which normally lead to processes of re-equilibration.

So they can be used also for some sort of forecasts. The case of Frankfurt is of textbook quality (Fig.7-3). Curiously Vienna "should" have more passengers to Frankfurt. For London (Fig.7-4), the "weak" connection is curiously Paris. In the case of Tokyo (Fig.7-5), there is a sort of saturation around 10^6 pass/year for Honolulu and Hong Kong. Maybe the Jumbo-1000 could help on these routes.

Anomalous distributions are shown by various airports in newly emerging countries, like Prague (Fig.7-6) and Hong Kong (Fig.7-7). In these cases the fractal ratio is not constant but increases rapidly. We could not identify a cause or some correlation for this behavior.

Fig.7-1

The flow of passengers in and out of the Munich airport can be modeled since 1950 with two logistic pulses. The first one is so to say normal. The centerpoint fits the Kondratiev, the ΔT is however too short. The second pulse is centered in 1987 and mirrors the second pulse in world air traffic.

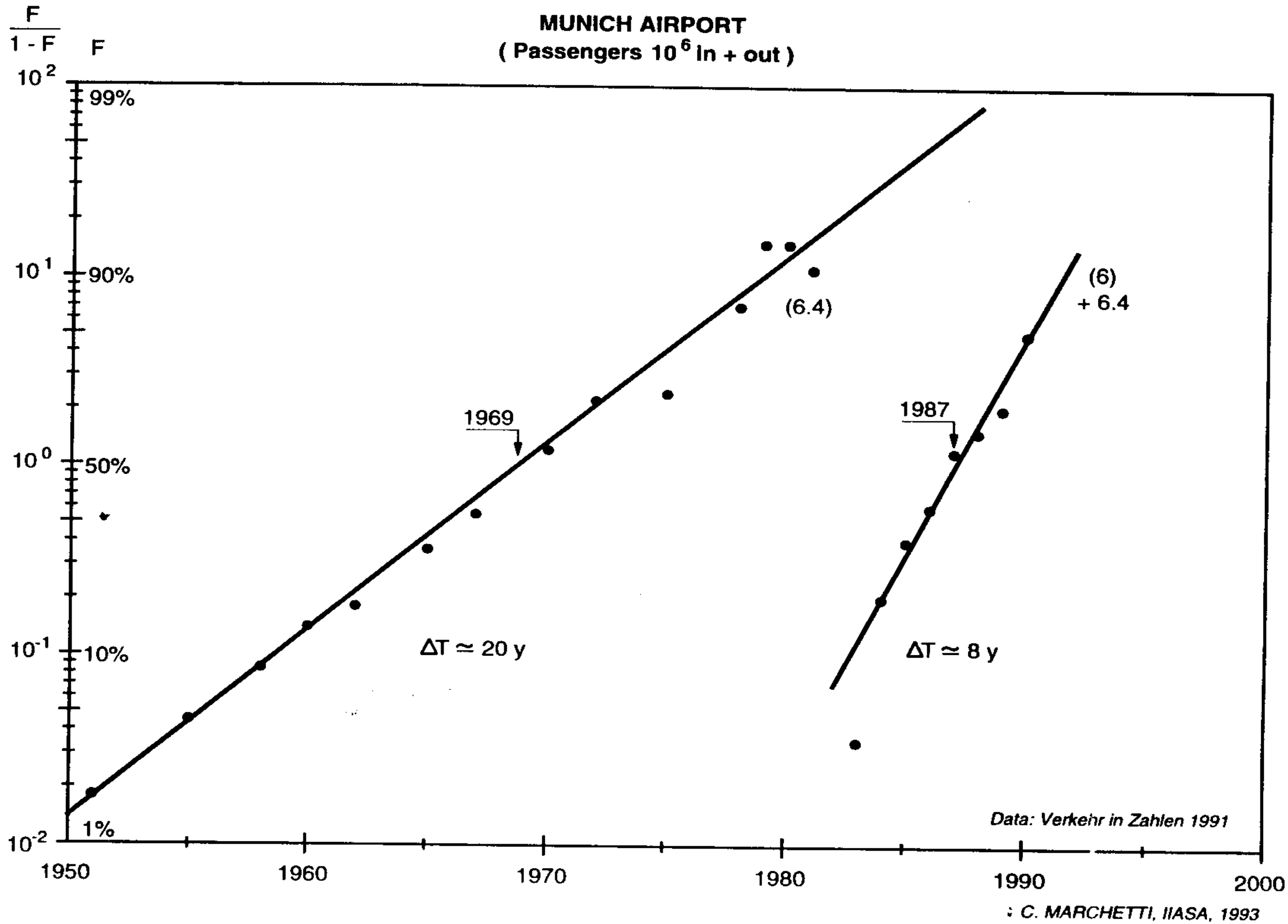

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Fig.7-2

The flow of airplanes in and out of the Munich airport can again be represented with two logistics, which is not obvious because larger traffic is normally dealt with larger planes. The first pulse is too early and too short for Kondratiev rules, meaning it saturates already in 1980. The second pulse fits nicely the hole, as it saturates in $1986 + 7 = 1993$. This kind of behavior is rare.

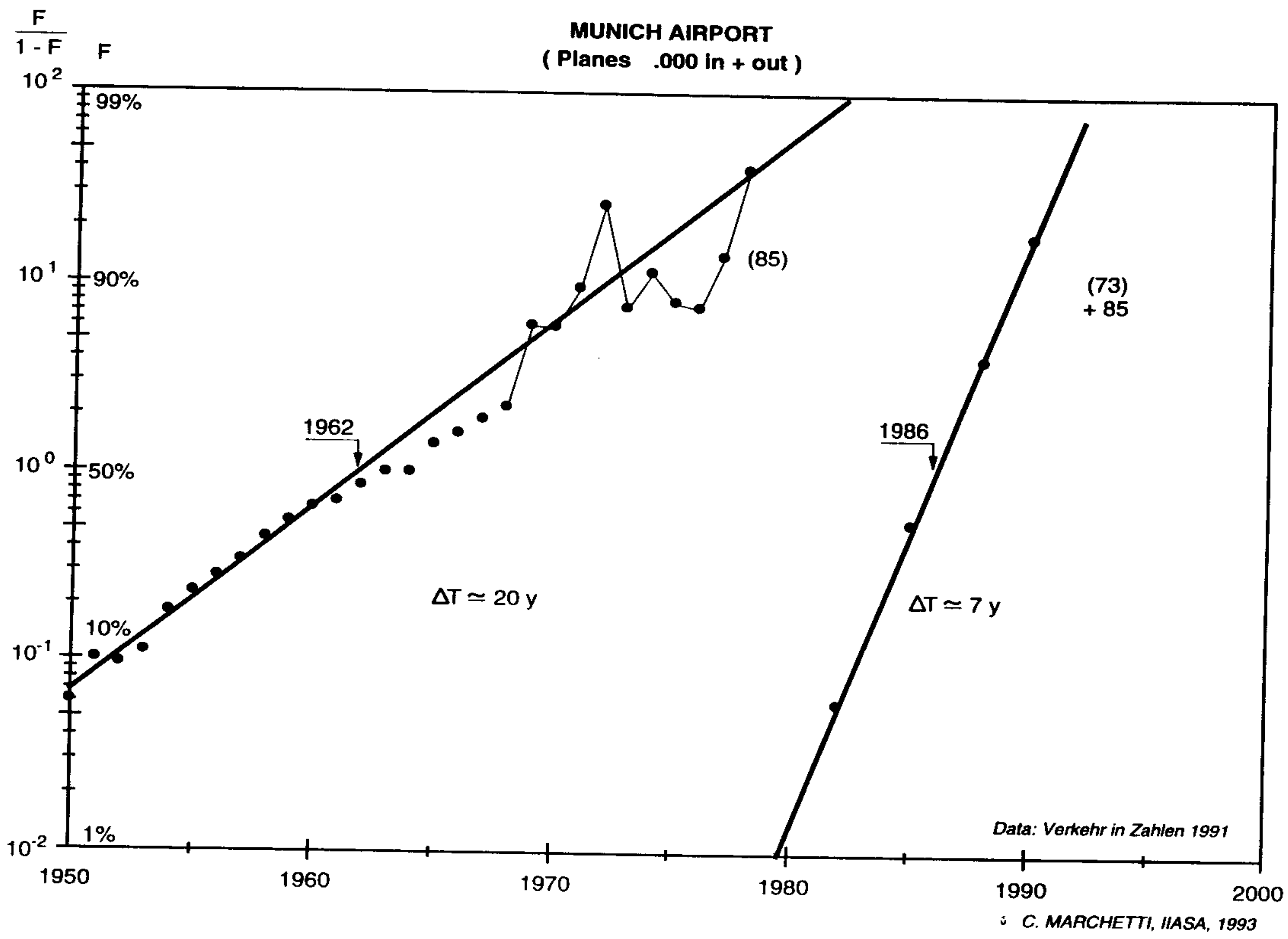

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Fig.7-3

The rank size analysis of destinations for passengers flying from Frankfurt show an almost perfect fractal distribution. Formally, the ratio between the number of passengers traveling to a destination of rank n and one of rank $n + 1$ is independent of n. This distribution is characteristic of structures "filling" spaces functionally. It was originally used by Zipf to order the size of American cities.

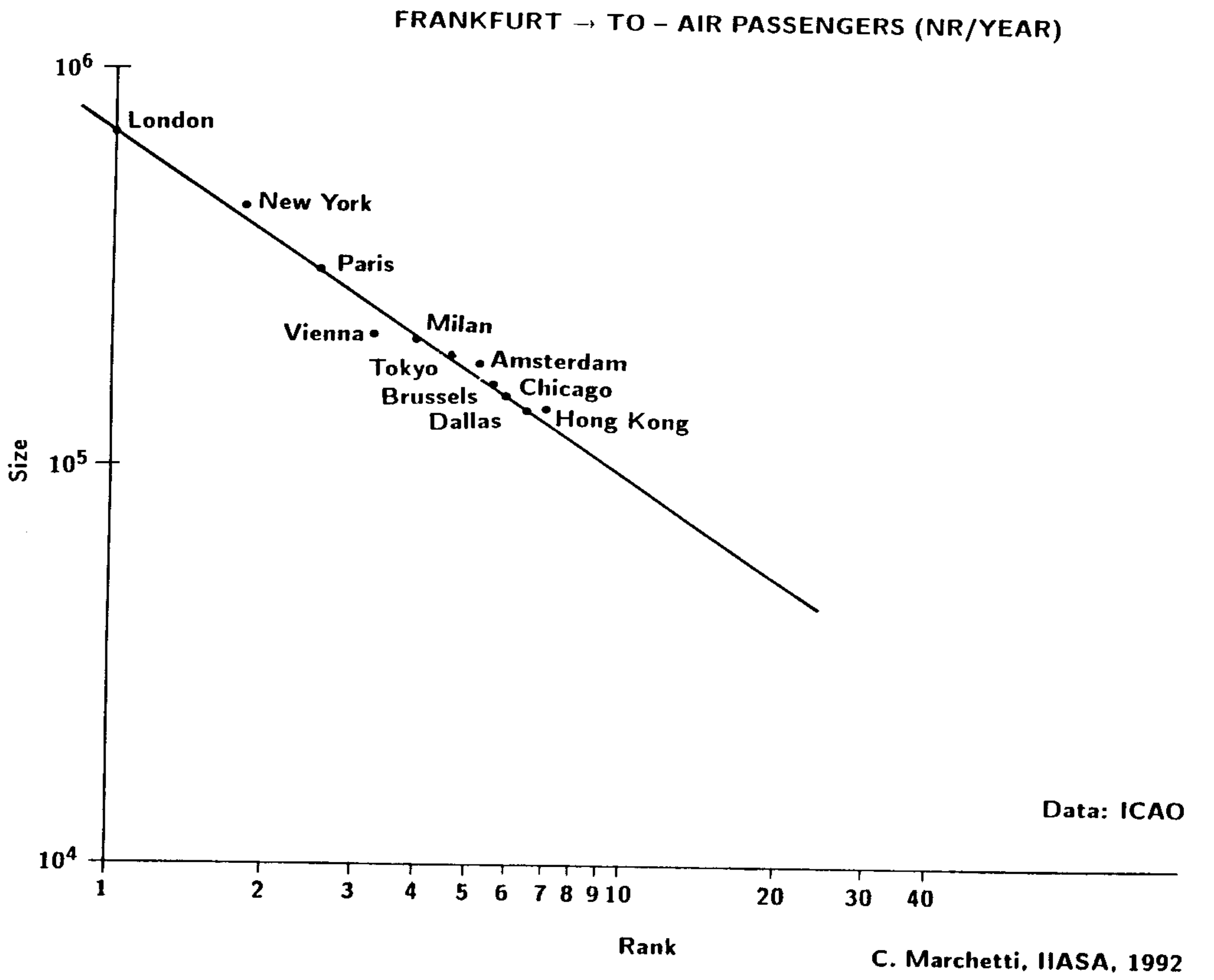
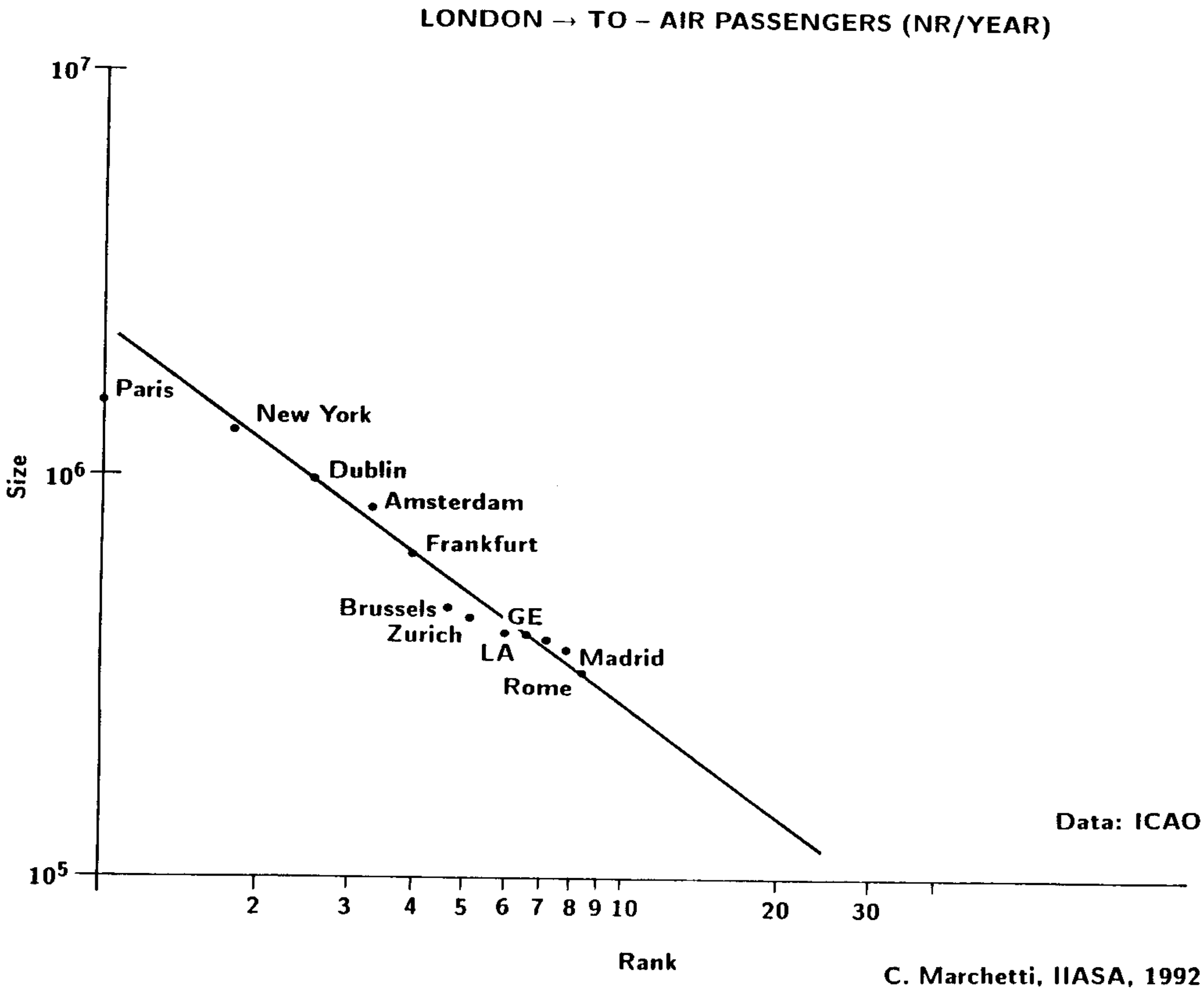

FRANKFURT → TO – AIR PASSENGERS (NR/YEAR)
London
New York
Paris
Vienna
Milan
Tokyo
Amsterdam
Brussels
Chicago
Dallas
Hong Kong
Size
10^6
10^5
10^4
1
2
3
4
5
6
7 8 9 10
20
30
40
Rank
Data: ICAO
C. Marchetti, IIASA, 1992

Fig.7-4

The case of London is not as smooth as that of Frankfurt. Paris seems strangely to get less passengers than her rank would demand, and also Brussels and Zurich are somehow underrepresented.

AIR - 222



LONDON → TO – AIR PASSENGERS (NR/YEAR)
Size
10^7
10^6
10^5
Paris
New York
Dublin
Amsterdam
Frankfurt
Brussels
Zurich
GE
LA
Madrid
Rome
2
3
4
5
6
7
8
9
10
20
30
Rank
Data: ICAO
C. Marchetti, IIASA, 1992

Fig.7-5

With Tokyo we have the example of a rank size distribution saturating for the first two positions in rank. This may be due to some physical constraints, as the passenger in both cases range around 10^6 per year.

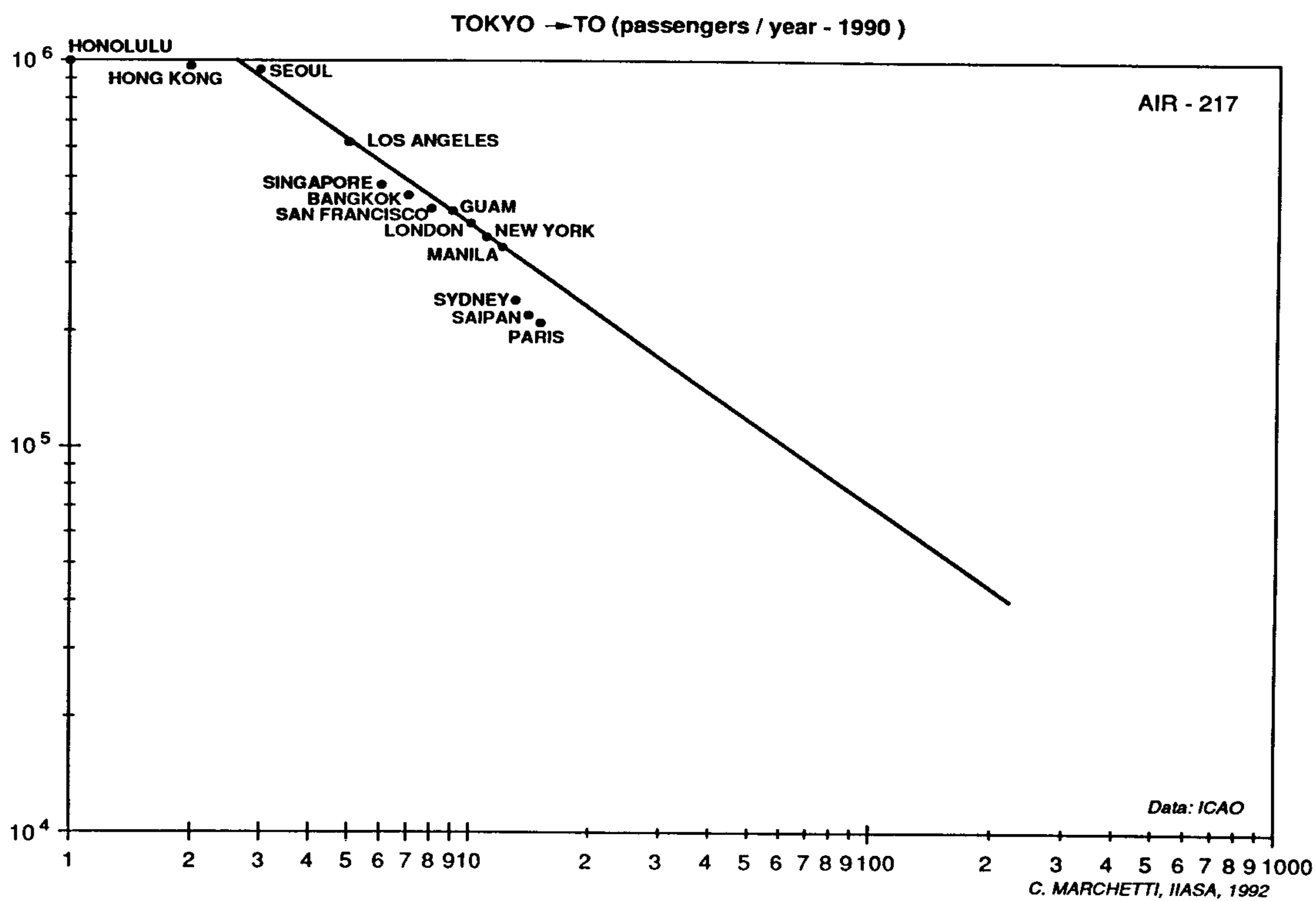


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Fig.7-6

We have here an unexplained case of continuously changing ratio in the rank size distribution. This is an indication for a state of disequilibrium, but it is not clear where the equilibrium should lead. Extrapolating from ranks of high n, the passengers to locations of low n would be excessive. It is difficult to imagine, e.g., 800.000 passengers going from Prague to Frankfurt per year.

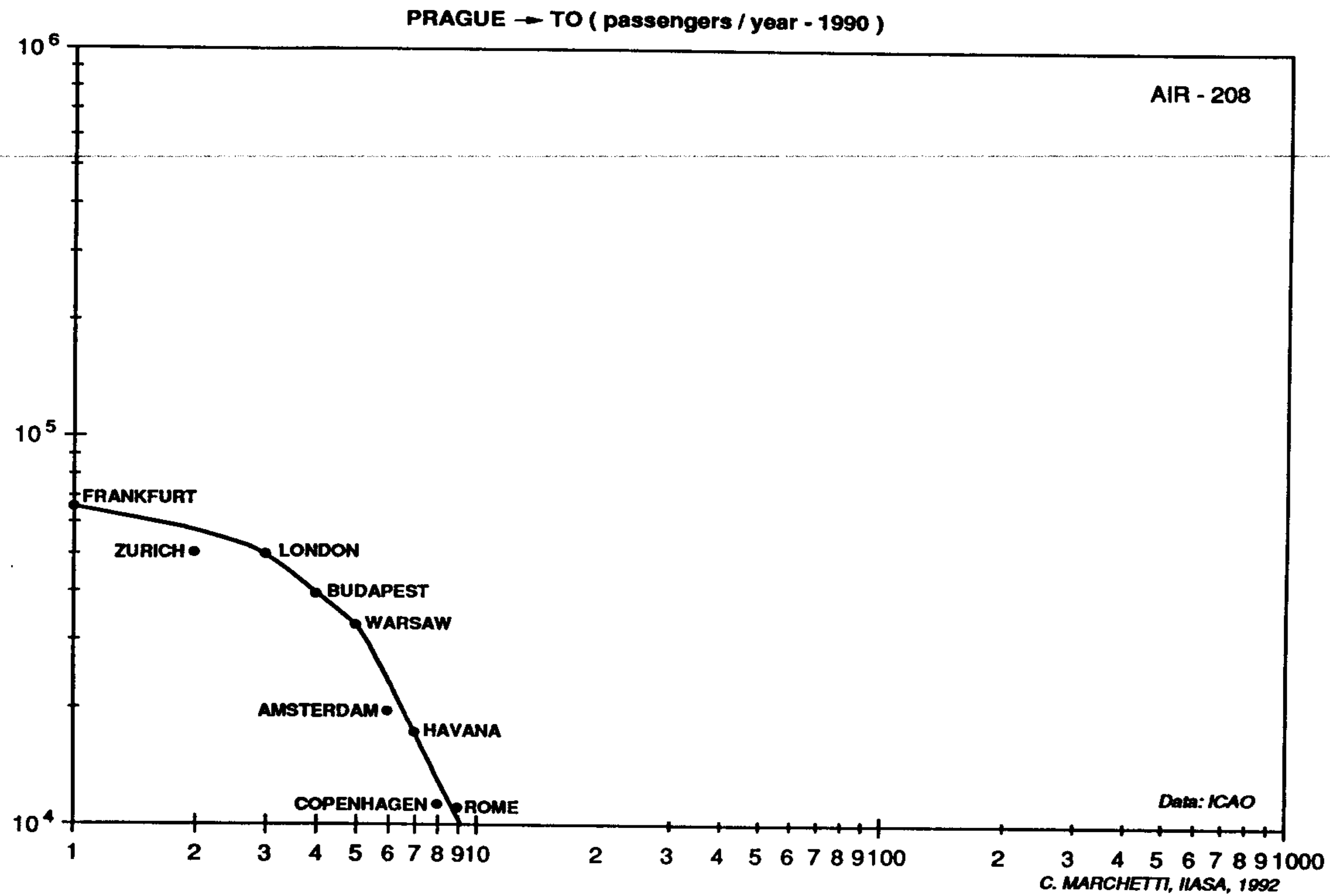

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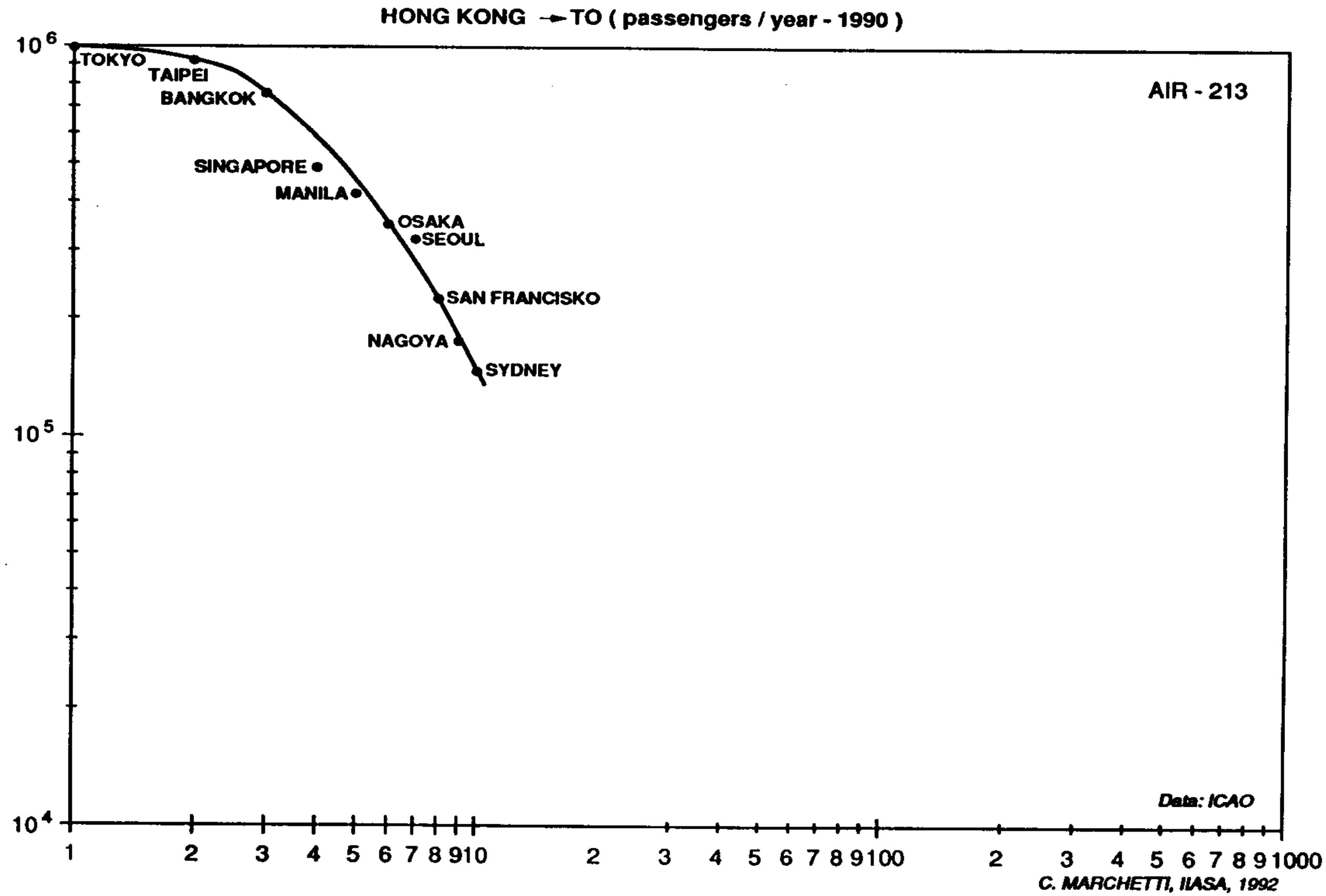
Fig.7-7

We have here an unexplained case of continuously changing ratio in the rank size distribution. This is an indication for a state of disequilibrium, but it is not clear where the equilibrium should lead. Extrapolating from ranks of high n, the passengers to locations of low n would be excessive. It is difficult to imagine, e.g., 10^7 pass/year going from Hong Kong to Tokyo (even with Jumbo-1000).



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