What They Need is Speed

Modeling Historical Evolution of Transport Demand to Forecast Air Transport

Cesare Marchetti
International Institute for Applied Systems Analysis
Laxenburg, Austria

MARCHETTI-050

July 1992

Introduction

The scope of this paper is to draw a forecast for the development of air transport up to the year 2020. To do that we had to go back to prime principles delving into the ways man adopts faster means of transportation incorporating them into the web of his anthropologic, cultural, and economic constraints.

The rules we extracted from the last two hundred years of transport evolution have been applied to the emerging technology of air transport. The outlook for the next 30 years appears brilliant and will require a rethinking of airplanes, airports, and city connections to process an increase in traffic by an order of magnitude.

THE PLAN:

1-0 Back to basic: Why do people travel? An *anthropological answer.*

2-0 Transport machines as prothesis to get speed. *Cars as the seven-league boots.*

3-0 Kondratiev 55-year pulses in the penetration of new technologies. The *pulse of aviation* will start in 1995.

4-0 Matching airplanes to traffic and airports to airplanes. the *continuous-process* principle.

1-0. On the Basic Principles of Travel Demand

Man is a deeply *territorial animal.* After all, history books mostly contain the description of territorial disputes; and lawyers have their hands full with neighbor squabbles.

One of the basic tenets of the territorial animal is that the territory has to be as large as possible. The rationale is that *resources and opportunities increase with territory size.* But also the effort and the dangers to exploit and defend it will increase, so that a balance has to be struck somewhere.

Every animal has its enemies, and roaming around in the open is dangerous. The problem is tackled by minimizing the *exposure time*, usually through the maximization of foraging efficiency. These exposure times tend to have constant means, for a given species. Extensive field studies originally made under the aegid of the World Bank shows that *for man* this time is about *one hour a day.* This across race and culture. It is a well-preserved *basic instinct*, like the 8 hours sleep.

It is curious to observe that even people in jail, who have nothing to do and nowhere to go, walk in rounds, *and in the open*, for about one hour a day.

Man is also a *cave animal* and, as we shall see, much of the success of air transport is linked to the trogloditic instincts of our managers. The cave, or its modern equivalent, the home, is a well-protected environment and people spend about 75% of their time there (Table 1). The mean is taken over the whole adult (> 10 years) population. The cave-man instinct of managers and businessmen drives them home at night. Trips have to be one-day, and that requires airplanes beyond a distance of a few hundred kilometers.

The last point is that house *expenses for traveling* are about *12% of disposable income* (Table 2). The stability of such a value over different incomes and different countries at different times makes one suspect another anthropological mechanism at work. A suggestion may be that if the hours/day dedicated to consumption were about 8, then one could postulate that one hour dedicated to traveling would have 1/8 of the budget corresponding to its time slot.

As Zahavi in his seminal work at the World Bank showed, travelers allocated their hour/day (Travel Time Budget), and their 12% of the disposable income (Travel Money Budget) between the different modes of transportation, in such a way as to *maximize distance*, or range, or *territory*, depending on the point of view from which their behavior is analyzed. In other words, TTB and TMB are carefully mixed to generate the final product, *Travel Distance Budget* (TDB), that will be freely allocated in view of the personal objectives.

Freedom has always some boundaries, however, and observing how the traveler operates we can see that he usually makes *a few round-trips* starting from his home. About three per day for dwellers of large cities, to five per day for people living in small centers. Also the allocation of the one hour time between the three trips is very skewed, with one long trip and two or more short ones. Usually the long trip is used to go to work, and this has a precise rationale (if subconscious as most of these things). Maximum distance between working place and living place ensures maximum range of choice for these two centrally important items. After all, people spend 85% of their time *into* them plus another 3% of

Table 1.

Characteristic sizes of daily budget, (a) mean for all persons, (b) for the group of housewives without cars.

Characteristic size of time budget	Daily budget elements of activities (Minutes per person and day)									
	(1)	(2)	(3)	(4)	(5)	(6)	(6a)	(6b)	(6c)	(7)
(a) Mean value for	German average person older than 10 years									
251 Work days	1046	182	14	49	31	65	19	30	16	53
50 Saturdays	1161	46	4	20	36	61	20	31	10	112
65 Sundays & holidays	1211	21	1	2	4	59	24	30	5	142
all 366 days 1976	1090	135	10	37	27	64	21	30	13	77
Maximum value	1314	232	29	89	66	90	45	50	31	211
Minimum value	975	0.5	0	0	0	36	9	16	0	24
Standard deviation	75	73	7	25	13	9	5	6	6	42
(b) Mean value for	German housewives without car									
251 Work days	1276	19	0	1	56	47	25	14	8	41
50 Saturdays	1255	10	0	1	48	50	23	21	6	76
65 Sundays & holidays	1260	4	0	0	5	57	27	26	4	114
all 366 days 1976	1270	15	0	1	46	49	25	17	7	59
Maximum value	1360	80	14	22	108	109	85	60	29	241
Minimum value	1097	0	0	0	0	22	10	2	0	5
Standard deviation	40	17	2	2	26	14	10	9	6	38

(1) At home.
(2) Work.
(3) Business.
(4) Education/training.
(5) Shopping.
(6) Traveling; (6a) on foot, by bicycle or motor cycle, (6b) in motorized individual traffic, (6c) with public transportation.
(7) Other.

Table 2.

Travel Money Expenditures

NATIONWIDE vs. Total Household Expenditures, %			
US	1963–1975	13.18 ± 0.38	
Canada	1963–1974	13.14 ± 0.43	
UK	1972	11.7	
West Germany	1971–1974	11.28 ± 0.54	
URBAN vs. Household Income, %			
		With Cars	*Carless*
Washington, DC	1968	11.0	4.2
Twin Cities	1970	10.1	3.4
Nuremberg Region	1975	11.8	3.5

their time to move *between* them.

This statistical-anthropological description of the *Homo mobilis* bluntly contradicts the image we have of unlimited mobility, people rushing day and night from nowhere to nowhere at crazy speeds. People, in fact, are very static and *90% of their traveling is done inside the "home range"*, defined as the distance you can reach in 30 minutes with your car, if you have one. Or the fastest public transport, if you don't; for example, commuter planes, where available. Mobile people like the Germans take a round-trip every second year on airplanes (mean over the population) and the Americans two per year. The mean distance for these trips is the same (about 1000 km) showing the dominance of the *territorial drive* over "country size" or other variables. The mean distance of trips by train is also the same in both cases (100 km) and it is in proportion of the relative speed of the transport modes (600 km/h for planes and 60 km/h for trains, both in the USA and in Germany). This shows the dominance of the *time parameter* over other variables in determining the taxonomy of traveling.

Remarkable between distant trips is a relatively very long trip taken *once a year*, usually under the disguise of a vacation (once it was a pilgrimage). The various cultural cover-ups, like getting to know other people or their cultural heritage, or admiring transparent seawater somewhere, do not meet the actual behavior of tourists who tramp over everything appears in front of them with little actual interaction. Hopping from Hilton to Hilton to taste local food is a good way of stigmatizing the situation. The problem is why do people *really* move long distances, stochastically, once a year, that way. Similar behavior can be found with the *Paramecium*, which periodically starts swimming in a stochastically chosen new direction and with cats and dogs who disappear fro a couple of days.

If we have to start a search on the subject, we would try the *exploration for new territories* as an archaic human drive. When tourists come back, their "dancing bee" behavior in describing the marvels of the territories explored lends support to this hypothesis. This time travel agents are flourishing on another *basic instinct.*

Coming back to the main result of the anthropological–phenomenological description of travelers' behavior, economic and technical resources are carefully put together to *maximize a personal Travel Distance Budget.* Then the traveler will allocate it into actual objectives. It must be clear that these objectives depend on the size of the budget, and when this increases also the *objectives are reallocated over larger distances.*

So the current reasoning that airplanes cannot substitute trains below, for example, 200 km is blown up by the fact that travelers who can afford airplane tariffs will fly 2000 km away *instead* of creeping 200 km with the same travel time. This is most evident, for example, for vacation trips.

2-0. On Transport Machinery and the Way People Use It

For eons man moved on foot. At about 5 km/h. The anthropological constraints we spoke about were fully active, determining the structure of human settlements and space organization. At 5 km/h, a round trip of one hour covers a distances of 2.5 km, the radius of the territory. Assuming a circular shape, the area is about 20 km^2. Looking at a set of Greek villages, the areas pertinent to them is about 22 km^2 (Fig.2-1). Walled cities up to 1800 never had a diameter larger than 5 km or 20 km^2. Persepolis, Rome, Marrakech, Vienna, reached that dimension. Venice, still a city on foot, has a 5 km diameter for the connected part of it.

The first machinery for personal transport were horses and carts. They always had a great importance for military and political objectives, but they were *too expensive* and their use limited to the top elites. Consequently, this technology did not penetrate the daily life and shape the structures connected to it. Still in 1800, a vital and powerful city like Berlin had a diameter of 5 km (Fig.2-2).

But since 1800 progress in vehicular transportation was explosive. The horse-drawn tram, on iron tracks, made horse transport in bulk possible, bringing the cost at the level of the then already richer popular purse. Then came the electric tram, the city train (subway or Schnellbahn), and finally the private car. The process took two centuries, bringing the speed from the 5 km/h on foot to about 40 km/h on car, and increasing the surface of the personal territory (*and of the city!*) by almost two orders of magnitude. It should be clear that it *makes no difference if the speed is provided by personal or public means.* The oldish and uncomfortable but fast Metro in Paris carries about 4 million passengers per day, most of which own a car.

We can look now at the details of the adoption of new means of transportation, as to acquire experience to forecast what will happen to airplanes. A good first synoptic view is given in Fig.2-3, where the distance/day/person *done on vehicles* is reported for France, since 1800. The procedures of adoption are here very clear. A new means of transportation enters the market providing a higher speed (trains versus horse).

Speed is expensive both because faster machines have always been more expensive than slower ones, per kilometer, but also because people travel on time budgets, and for the same time they make more kilometers. Cars and planes cost more or less the same in the USA, per kilometer. But per hour a plane costs ten times as much. Allocation of time from TTB is cautious because of disruptive action on TMB. Americans dedicate about 50 seconds/day, mean over the population, to air travel, and about 50 minutes/day to car travel (in 1940, the minutes on cars were 20/day and the same value can be estimated for the time spent on horse-drawn vehicles in 1920).

Speed being expensive the *new means of transportation* is *absorbed slowly*. For about 50 years it takes only the growth in travel all for itself, and another 50 are needed to sweep the competitor out of the market. We see that with railways blocking the growth of horse transport around 1850, and phasing it out in 1900. Motorized road transport blocked the growth of railways (in terms of passenger kilometers) around 1930, and we may expect to phase them out after year 2000. With the same logic air transport should now take the growth, blocking the increase in road transport. *This logic is very important for estimating the expansion of air transport during the next 30 years.*

The chart of Fig.2-3 is strategic in visually conveying the secular structure of the basic trends. The analysis can, however, be much refined by zooming into the detailed processes, using the more sophisticated tools of systems analysis. A glimpse into the substitution of horse -drawn omnibuses with motor-buses in Britain is given in Fig.2-4. The straight lines actually represent diffusion logistics (see Appendix). Here we focused on a limited sector of the transportation market, and on a limited area. But we can repeat the exercise on a broader scale, looking, for example, at the evolution of the infrastructures that support the transport machinery (Fig.2-5), monitored through their length. Length of canals, railways, and paved road in the USA is here reported fitting the data with logistic equations. We see here that the system is splendidly self-consistent. One single and very simple equation can describe *the whole process* of expansion of an infrastructure, an internal regularity not apparent in charts of the type reported in Fig.2-4.

Fig.2-4 also contains a detail of great importance and generality: the central points in the development of these infrastructures are spaced exactly 55 years. *These 55-year cycles, a generalization of Kondratiev economic cycles, haunt all sorts of human activities, from air travel to homicide rates*, and will play an important role when we look at the future development of civil aviation.

Coming back to our *travel protheses*, what we normally observe is that people distribute their time and money budgets between the different modes, ordered in terms of increasing speed, and tries to privilege the faster ones. The fastest is usually very expensive and the most used is the second best. *In our times this is the car.* When a person can take hold of a car he will, in fact, spend on it most of the hour of his travel time budget (Fig.2-6). But car speed seems to be bound to stay around 40 km/h as the yearly mileage per car clearly shows (Fig.2-7). This means that the increase in mileage of 3% per year as shown in Fig.2-3, which has been fed during the last 50 years mostly by the expansion in the number of cars in use, will whither when everybody having a license has also a car. A situation almost reached today in Western countries.

The faster means of transportation coming next to the automobile is the airplane. But for the moment being it is far too expensive to make a dent into the time budget. As already said, Americans spend 40 seconds/day, mean, on airplanes (and 50 minutes on cars). Europeans 15 seconds/day. Because the purchasing power of Europeans is comparable to that of Americans, the difference in use may be reduced to a difference in fares, which in the USA in the mean are just about 4 times lower than in Europe.

Assuming that travel on all transport modes keeps *increasing by 3% per year*, the mean distance traveled per day being today about 40 km/person (the speed of the car which is used one hour per day), travel distance *during the next 30 years will increase to almost 100 km/person/day.* If the extra 60 km were made on airplanes with the present mean speed of about 600 km/h, this would signify *6 minutes/day allocated to airplanes*, mean over the population. The hypothesis of 3% growth which went unabated for 200 years may well hold for another 30 years. Some of the speed can be gained by moving the slower modes faster. Metros are faster than cars in large cities, and they can be made faster by using new technologies like the Magnetically Levitated trains (Maglevs) now under field testing in Germany and Japan. Trains are trying to join the fast league, by the introduction of TGV. Cars were mysteriously stuck to the 40 km/h since Ford's times, and all technical ingenuity poured into new models just compensated the effects of increasing density. The various improvements in speed will reallocate customer's choice between modes, and taking into account that airplanes will snatch sizable time shares out of the traveling hour, we may safely assume that the total km/day on cars will stay basically constant, as in the previous mode shift (horse → train, train → car).

Now the conclusion is that *with the above assumptions during the next 30 years air transport will expand by an order to magnitude.*

The logistic problem linked to such an increase in traffic, think of the clogged airports nowadays, may be appalling. *The system has to be rethought from scratch* and we will give some reflections on that. But from the point of view of the individual traveler the hectic is not visible. He will keep traveling one hour per day, but at 100 km mean speed. His territory will increase by 2.5 in linear size, or about six times as large in terms of area. During the last 200 years the territory went from 5 × 5 km^2 to 40 × 40 km^2, an increase by about 60 times.

It must be clear that the airplane will not substitute other means of transportation on the same routes. *Having a larger Travel Distance Budget we reorganize the use of territory* and consequently the points of destination which will tend to be located farther away. In a sense our mental image of the territory is in terms of traveling *time*, and consequently it will expand more or less homothetically with the transport speed available, like the city of Berlin we discussed before.

The time consumed for long-distance travel will be subtracted to short-distance displacements. One of the consequences will be the reduced use of cars, after they will have saturated, as today for Western countries.

3-0. On the Taxonomy of Change: The Kondratiev Cycles

The analysis of the development of infrastructures in the USA reported in Fig.2-5 gives us a first hint of the fact that the system may have high levels of invisible order (see, for example, the perfect self-consistency of the growth process) and a rhythm in the process of absorbing innovation. If we look at the introduction of basic innovations as described by Mensch, we find, in fact, that they come in pulses spaced again about 55 years (Fig.3-1). New transport modes are basic innovations and should stay in the ranks. In fact, each of the three historical waves yielded a new transport mode: train, car, and plane. In the case of energy, they yielded coal, oil, and gas. The present wave yielded nuclear energy. For transport a likely candidate is the Maglev.

Once introduced, the new technology has to penetrate the market, and also this is done in pulses, We can report the case of car penetration in the USA and in Europe, just to illustrate the paradigm (Fig.3-2 and Fig.3-3). We can also look at very synoptic indicators like total energy consumption and electricity consumption to reveal the pulse as a continuous signal. An analysis on the deviation from the secular trend for total energy and electricity was done by Stewart (Fig.3-4), showing very neatly the effect of the pulses. We adopted this chart as an "activity clock", to measure the situations in terms of their phase. An example is reported in Fig.3-5, where the center points of the innovation waves of Fig.3-1 are located on the clock chart, where they appear to occupy exactly the same phase position, for these three Kondratievs. We found convenient to take the *lowest points in the chart* of Fig.3-4, as the *starts and ends of the cycles.*

These low points are approximately 1830, 1885, 1940, *1995*.

One of the observations that will be important for our logic is that penetration may start at any point along the cycle, but almost invariably saturates at its end. See, for example, the first pulse of growth for cars in the USA and in Europe. Civil aviation started in the thirties, at the level of aerotaxis, if seen from today's technology, but with a well defined network of city connections, reproducing the core of today's intense traffic routes. Civil aviation as an industry really started with the DC-3, and developed along a logistic (Fig.3-6) almost perfectly encased into the present Kondratiev (1940–1995). The pulse saturates in this decade at 290 10^9 ton-km transported. It was 260 10^9 ton-km in 1990. The figure includes Russia and nonscheduled services. The analysis was originally done using data up to 1985. It happens, however, that after this date there is a sizable divergence between the actual values of air transport and the fitting equation. This may be due to "instabilities" that often occur near the saturation point, where actual values oscillate around the asymptote of the logistic. But it may be possible that this is due to a second pulse, very fast and again saturating around 1995. We note that, but are not reporting here, the status of this analysis as it may not be essential to the definition of the broad lines of development of civil aviation during the next 30 years, which is the objective of these notes.

Another way of looking at the pulsations in energy consumption is to decompose the growing energy consumption worldwide into a sequence of logistic pulses which grow in sequence one on top of the other. The exercise is reported in Fig.3-7. The pulses are clearly contained in the Kondratiev cycles. The second one with its extreme irregularities shows what historians have slowly come to realize, that the "World War" was a 30-year war (1914–1945) and the economy of the peaceful interval hat war characteristics. (We have many other indicators naturally, pointing to that). By making some assumptions we have also constructed the evolution of the total distance between ticketed points for US airports, calling that *network length* in the same sense as the length of paved roads. The exercise is reported in Fig.3-8, using the Fisher-Pry transform (see Fig.2-5 for the first three pulses in linear form). The "Kondratiev invariant" position of the flex has been used to fix the maximum rate of growth for the network in 1995+7 or in 2002. As the interconnections between large cities are already in place, the expansion may come by linking small cities to hubs, or by introducing selfcontained commuter lines. The expansion of the purchasing power, and the reduction in air travel cost, must finally come to the popularization of air commuting.

Fig.3-8 contains also a fifth line, marked *Maglevs*. The logic for introducing a new technology of transport is that a new Kondratiev wave usually calls for a new technology. The logic for putting Maglevs in such a wave is that the new technology can be superior to the previous one in some essential characteristics. Maglevs can have the same speed of airplanes, sub- and supersonic, *but on shorter distances.* A Constant Acceleration Maglev (CAM) could cover the distance Bonn–Berlin in about 10 minutes with accelerations-decelerations of 5m/sec^2 (0.5 G). Only a hypersonic plane could do that, but certainly not over a distance of 500 km . The Maglev in question should move in an evacuated tunnel with equivalent air pressure of 15.000 meters, as a Hypersonic. Maglevs are developed in Germany and Japan but this particular technology is studied in Switzerland (project Swissmetro). The second point where Maglevs are superior is *capacity.* The vehicles are completely passive, under control of the computer that regulates the magnetic fields on the track, supporting and pulling the vehicle. This means launching a vehicle every 20 seconds appears possible. The distance at start between vehicles would be 1 km with 0.5 G acceleration. With trains carrying 500–1000 people, peak capacity can be above 100.000 persons/h on a single line between two stops. Maglevs, like airplanes, must carry people basically between two points with no intermediate stop otherwise their time advantages would be reduced or lost. Maglevs are then perfectly suited to *take over* from planes the *routes most heavily trafficked.* Like where air shuttles are in operation, to start with. They can also create high density routes by providing hypersonic service over short distances, like the quoted example of Bonn–Berlin. This route, operated with a transit time of 10 to 20 minutes, could generate about 0.5 million trips per direction *per day* by functionally fusing the two cities.

Coming to the extension of the networks, such sequences of logistics for single technologies can be integrated in a superlogistic referring to the collective purpose (network length of *infrastructures for transport*). On purely taxonomic grounds one can forecast to a point the characteristics of network to come. For example, length grew from canals in the USA (sat. 7 10^3 km) to railways (sat. 5 10^5 km) to paved roads (sat. 6 10^6 km) which reached the maximum. Air transport *network* will finally double with respect to the present one (in the USA) but will be much shorter than paved roads. Maglevs may come in the same ballpark as canals, linking only very intense corridors.

Most of the previous considerations have been made referring to passenger traffic. It is true that passengers constitute the bulk of air transport both in terms of weight and income from fares; just like when steamboats were introduced and sailships carried the bulk. Cargo has mostly been a sideline, first in the form of mail when air planes were small and weak. but with the advent of the 747 and its generous cargo bays, freight transport has picked up to the point that a number of planes operate as specialized freighters.

In spite of the fact that the two most successful long-range carriers, the 707 and the 747 were originally born as military freight carriers, they were, in fact, intended as civil planes. A real civil freight carrier has yet to be designed. The level of traffic may justify the expenses in our time horizon of 2020.

It must be clear that good transport technology follows the same rules as for the transport of people. Fig.3-9 clearly parallels Fig.3-2. Both are for France but the process is general. The next medium is faster and more expensive and progressively substitutes the old one when the value of merchandises increases, per unit weight, and the cost of transport decreases, with technical progress and volume. Like in the case of people, light and expensive goods travel by plane (Fig.3-10). This is obvious for electronics of all description, and also for expensive apparel. But raw textiles may do. In fact, it is extraordinary that fruit are routinely carried from South Africa to Europe with mark-ups of 1 or 2 $ per kg. Because the trend is toward larger and cheaper airplanes, possibly of specialized make, the spectrum of goods entering into air transport may grow very fast. On the other hand, the much ventilated idea of "dematerialization" of our society simply means that value-added per unit of weight keeps increasing. More properly one should say that "dematerialization of value added". These two convergent processes may lead to a progressive subtraction of freight from trucks, leading to a stabilization of their level of business in terms of ton-km (like for rail after 1940) and reducing them to local retailing after 2050.

Because the largest traffic may develop at short distance (1000 to 3000 km), the cargo airplanes should be large and light with cargo capacities of perhaps 500 tons, and take-off weight of perhaps 800 tons, roughly the double of a 747. This take-off weight may not constitute a problem for the runways as they are designed today.

4-0. On Airplanes

The most important parameter of an airplane from the functional point of view is its *productivity* which can be defined as the *product of capacity* (e.g., number of seats) *by speed.* It comes out as a flux: *pass-km/h.* Air travel *per se* can be defined as a flux if seen in the statistics as pass-km/year. One can divide that number by 10.000 and get the pass-km/h homogeneous with the units measuring the productivity of airplanes.

A historical analysis (Fig.4-1) shows that airplanes productivity always runs parallel to traffic flux. One of the interesting consequences is that from 1950 on, in spite of an increase in traffic flux by a factor of about 40, the number of commercial planes stayed remarkably constant, around 4000. This rule has been broken during the last ten years or so, our opinion being that large planes were not available in sufficient numbers.

The parallelism between productivity and traffic flux seems very rational as it *keeps vehicle congestion stable.* It can also be verified with oil tankers, whose number tends to be independent of the commercial oil flow over the oceans, and which again is around 4000. Accepting this point means that an increase in traffic by a factor of ten may require an increase in plane productivity again by a factor of ten.

This arithmetic will create problems. Planes operate at different hierarchical levels, basically four, although a fifth level is developing. Curiously the ratio in productivity between planes at successive levels upward is about 0.62 or the golden ratio. For jets which have more or less the same speed, the number of seats can be 450–280–170–100. Anybody can recognize famous makes carrying these numbers.

Multiplying by ten these figures makes no easy machine to engineer.

Let us start from the first level now occupied by the 747. This first level is reported in Fig.4-1 where the makes are positioned by their productivity. With the increase in traffic airplanes became larger, and larger planes require more powerful engines. The development of engine capacity is reported in Fig.4-2. Piston engines are characterized by their HP, and jets by thrust (lb or kg). Piston engines capacity grew logistically to a saturation point around 4000 HP. Their central problem was that of fluid flow. The complicated tubing and batch processing made air flow, i.e., power, limited. Jet engines operate with an unimpeded air flow, tendentially straight; they can gulp two orders of magnitude more air and reach one order of magnitude more power. Their problem is physical size. Apart from the sheer bulkiness, their power grows as the square of linear dimensions, but mechanical problems grow as the cube. The concept, shown in Fig.4-2, appears to have deployed already most of its potential. However, one way is left open: that of moving engines faster. If we go, for example, to mach 7, the engine will gulp an order of magnitude more air than going at mach 0.85; the airplane also gets a productivity ten times larger for the same size. That way one can perhaps solve the problem of a × 10 productivity for the first level.

The second level should carry, say, $280 \times 10 = 2800$ people. Deplaning such slugs will create a certain congestion at the bays, but let us look at the planes. Carrying 1000 people is no problem, and a beefed up 747–1000, already designed, could do it. This jumbo–1000 would carry passengers on three levels, like the old steamers. Multiplying such capacity by three with constant engine power means making the airplane plus fuel much lighter and the aerodynamics more sophisticated.

With new engineering and materials one can make air frames lighter and lighter following the historical trend. Aerodynamics and engine performance reduce the demand for fuel, and proportionally the fuel weight transported. Hypersonics are bound to use liquid hydrogen (LH_2) which is three times lighter than jet fuel. Its use may spill down in subsonic planes. Airbus industry is actually tinkering with an LH_2-fueled plane for medium range. A 3000-seat plane should lift 300 tons with passengers only. A 747 lifts now more than 100 tons of payload and a Tupolev 200. Our ambitious objective does not seem out of reach even if only patching up present technology.

Taking some cuts on numbers, a 747 at take-off may weight 400 tons, of which 100 tons are the paying load. The other 300 can bi divided half–half between fuel and airframe. In our super-747 (operating at second level!) the paying load should be 300 tons, as said. The volume of the plane might be twice as large, but in the name of progress in engineering and materials, we keep the weight constant. Fuel consumption will decrease due to more efficiency in propulsion and in better aerodynamics. Even not including LH_2, and because a second level is relatively short range, we can make 50 tons for the fuel. Total weight would then come out to be around 500 tons. This means that runways can be the same as today for the second level down.

When new problems come, that even the best patch-up of old technology 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 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.4-3). They are really hovercrafts without aprons, air being trapped dynamically under the stubby wings. According to Russian sources, where some prototypes have been built, 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 on water, however. But 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 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 University 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, Fig.4-4.

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.

4-1. On Airports

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 *airport structures and passenger flow have to be rethought from first principles.*

Now what must 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 a 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.

- The tarmac where the planes are parked could be a big circle from which runways radiate out much like Kennedy airport in New York.
- 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.
- The ticketing process should be in the plane, as it is often done 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 identifications of the traveler, including secret codes, so that a vendor machine on trains or at stations connected to the reservation computer can issue the reservation-entrance tag for the bay.
- People suffer in parting from their luggage and luggage should be carried in the cabin (all stairs are mechanical) and stored perhaps in 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 choices: city, parking lots, taxis. 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 sidestep for stopping, with one lane left for trains to move continuously. People changing 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 bay is recognized, and the train stops there. The wagon can come from the city, from the parking lot, or from the taxis, all 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 be 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 bay. Slotting again he will get the embarkation card and pass to move into the airplane. When seated he will pay 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 bay. 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. Although people arriving too early may clog the bays before the plane open gates. But it is their fault. In any case, the *souk* will absorb any time and any money available.

Appendix:
The Mathematical Methodology

The mathematics used in this analysis is extremely simple. Because historians may not be familiar with it, we add this note for illustration. The basic concept that *action paradigms* diffuse epidemically, is condensed in the epidemic equation:

$$dN = aN(\overline{N} - N)dt$$

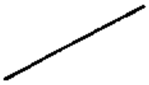
saying that the number of *new* adopters (dN) during time dt is proportional (a) to the number of actual adopters (N) multiplied by the number of potential adopters ($\overline{N} - N$), where $\overline{N}$ is the final number of adopters.

The integration of this equation gives

$$N = \overline{N}/[1 + \exp -(at + b)]$$

which is the expression of a logistic S-curve well known to epidemologists and demographers. *We apply it to ideas.*

In the charts of the present paper the logistic equation is presented in an intuitively more pregnant form. N is measured in relative terms as fraction of $\overline{N}(F = N/\overline{N})$, and the S-curve is "straightened" by plotting $\log(F/1 - F)$ (Fisher–Pry transform).



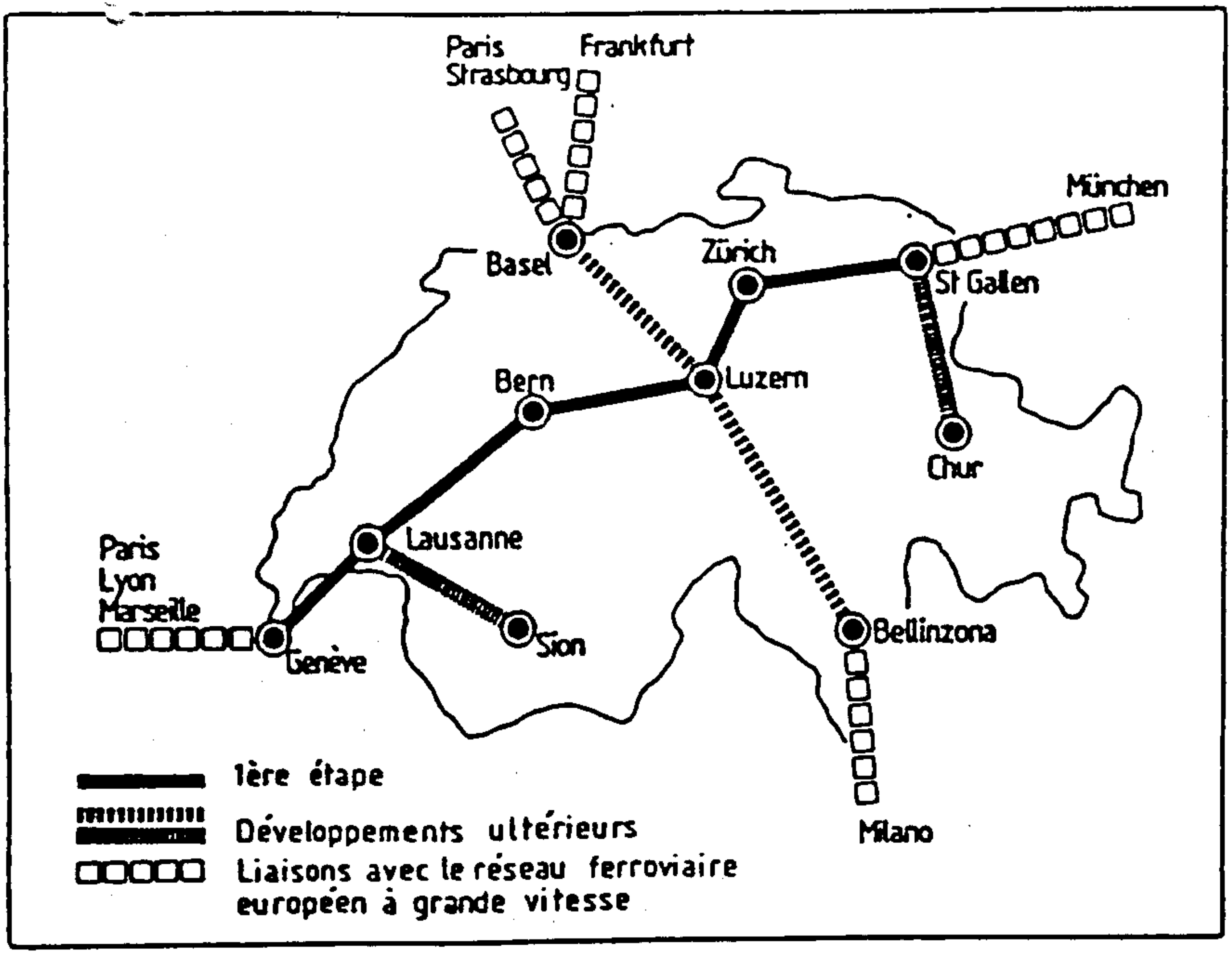
$$\log(F/1 - F) = at + b\ .$$

The time constant ΔT is the time to go from $F \simeq 0.1$ to $F \simeq 0.9$. It takes the central part of the process (80%) and the relation between ΔT and the a in the equation is $\Delta T = 4.39/a$.

The central date T_0 is defined as b/a .

The final number of adopters $\overline{N}$ is given as a number in parenthesis.

Fig.4-4



Réseau Swissmetro envisagé

Fig.4-3b

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

CRAIG COVAULT/WASHINGTON

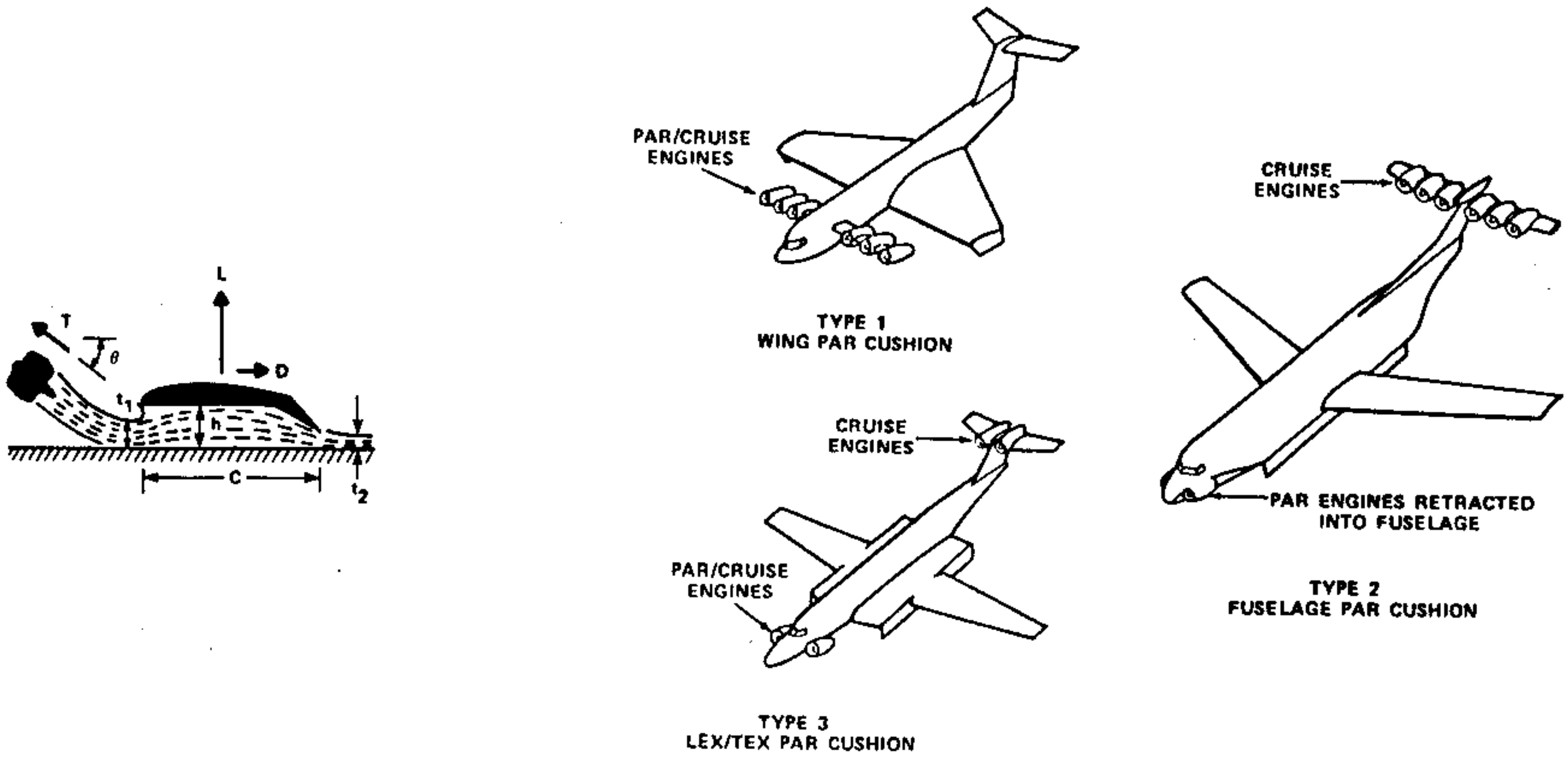
A proprietary U.S. team of contractors is studying development of a 500-ft. transoceanic/wing-in-ground-effect (WIG) aircraft that could carry 2,000 passengers and 1,200 tons of cargo at 400 kt. The concept was pioneered by the 300-ft. Soviet "Caspian Sea Monster" shown here.

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

Fig.4-3a



TYPE 1
WING PAR CUSHION

TYPE 3
LEX/TEX PAR CUSHION

TYPE 2
FUSELAGE PAR CUSHION

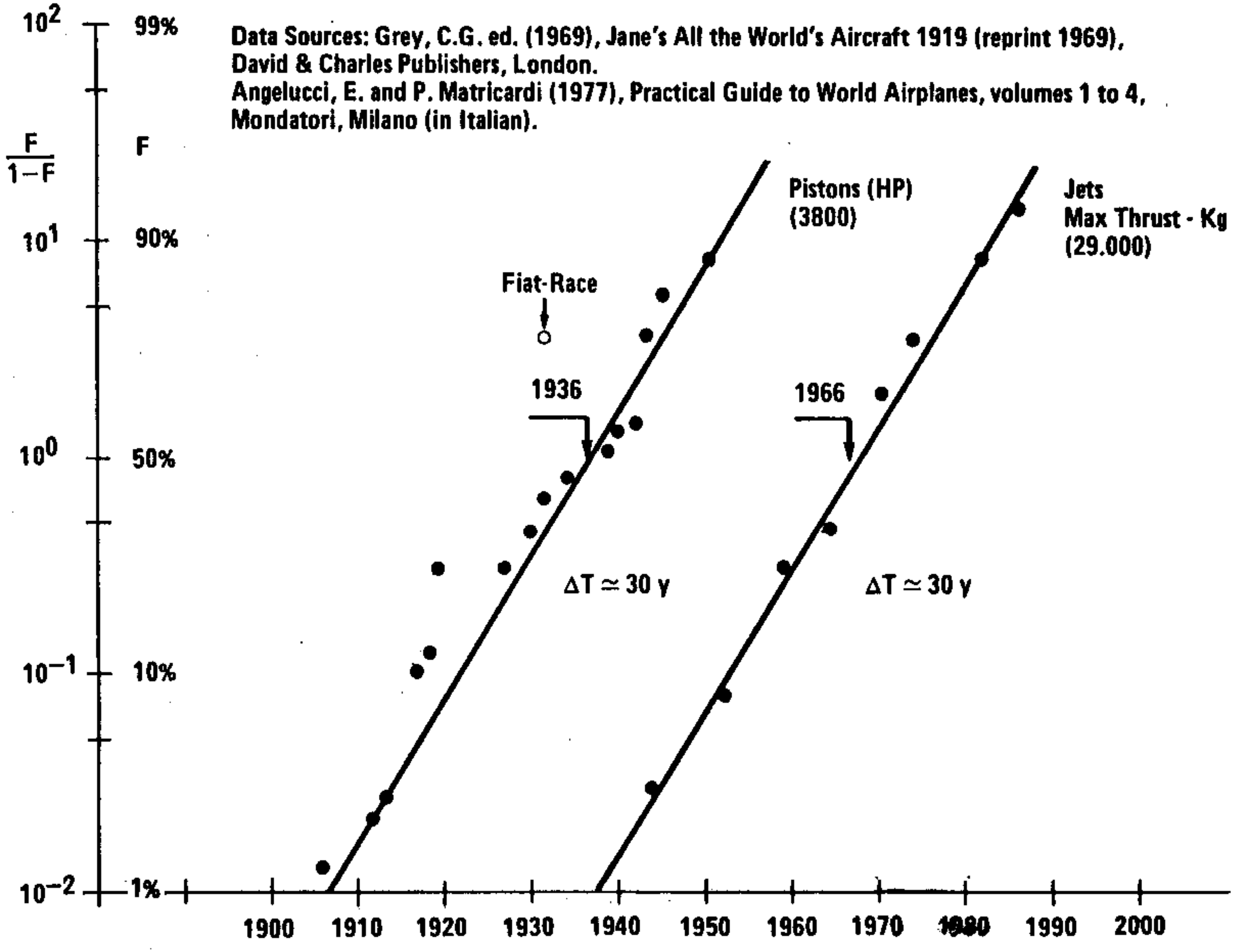
Fig.4-3b.

According to most recent news WIG principles 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.

Fig.4-2

AERO ENGINES CAPACITY (WORLD)

Best on Market



Data Sources: Grey, C.G. ed. (1969), Jane's All the World's Aircraft 1919 (reprint 1969), David & Charles Publishers, London.
Angelucci, E. and P. Matricardi (1977), Practical Guide to World Airplanes, volumes 1 to 4, Mondatori, Milano (in Italian).

Fig.4-3a.

When problems become unsolvable with old technologies, usually a new one comes to rescue. For very high productivity planes WIGs (Wing In Ground effect) open 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.

Fig.4-1

PASSENGER AIRCRAFT PERFORMANCE
(1000 Passenger – km/h)

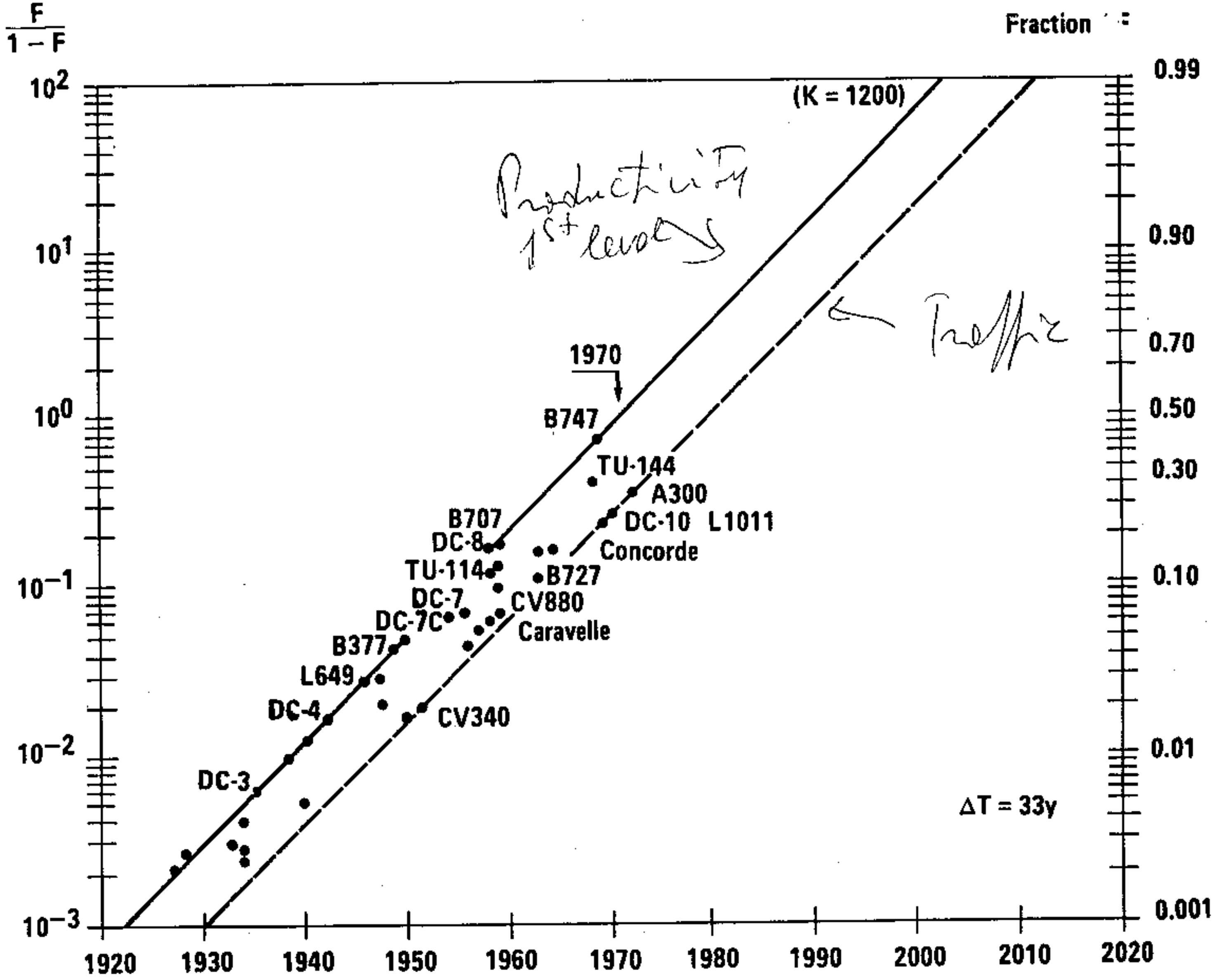


Fig.4-2.

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 and at that time jet engines were introduced to provide the needed power. But at present also jet engines are out of breath. More power could be obtained by inhaling more air through higher speed. Hypersonic planes seem on the cards, also for this reason.

Fig.3-9b

FRG – Imports of Manufactured Goods

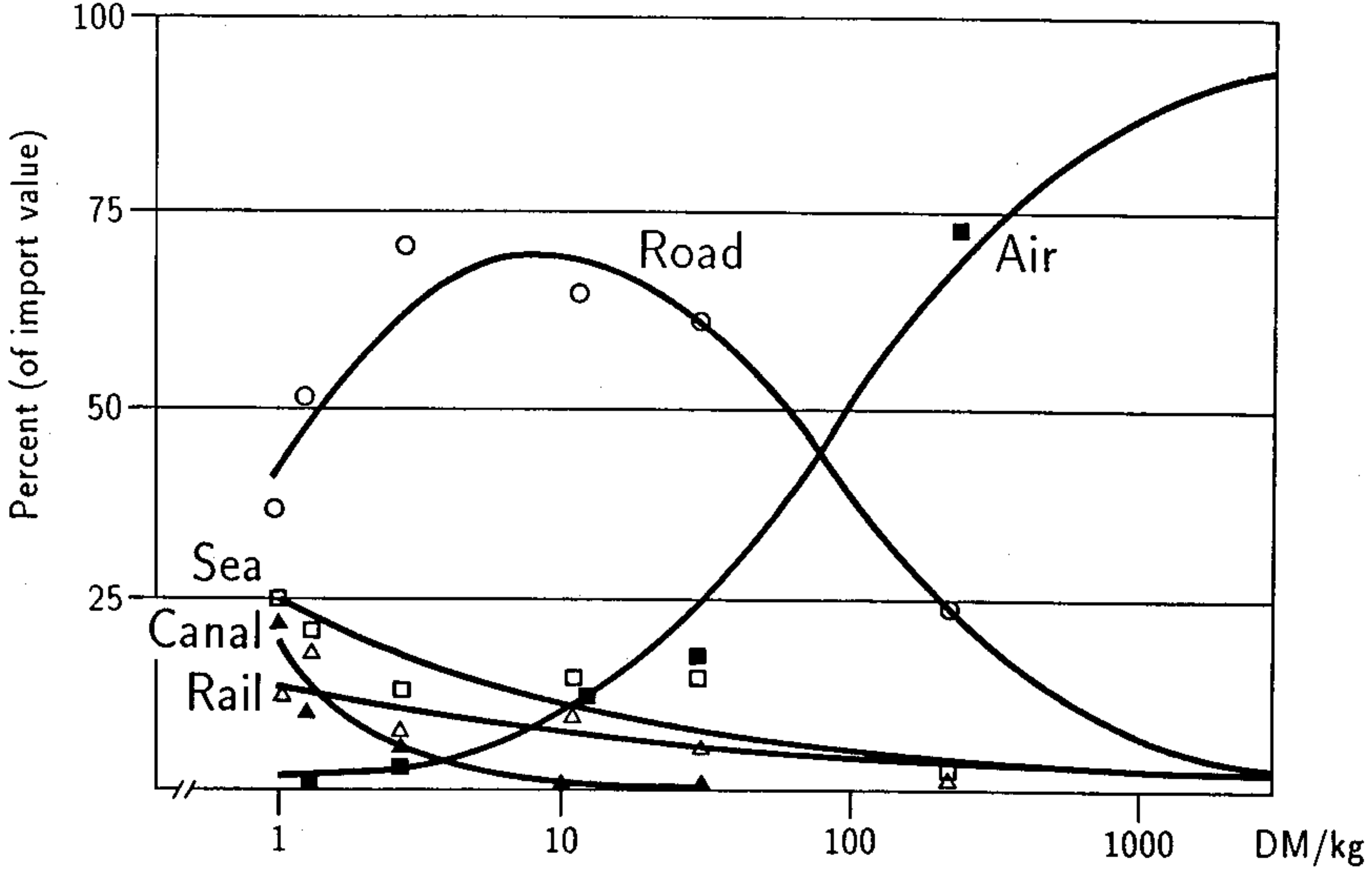


Fig.4-1.

The parameter which best represents a plane from a system point of view is its productivity, defined as pass-km/h. This productivity is a flux, homogeneous with the target of air transport which is defined in terms of pass-km/year. We can then compare the two fluxes, and find that they run parallel. This means that planes' productivity – in the chart first-level makes are reported and interpolated – grow in proportion to *world* traffic. One of the consequences in the past was that the number of commercial planes was always about 4000, in spite of an increase in traffic between 1950 and 1985 of about a factor of 50. As explained in the text, a new pulse in productivity can be obtained by going hypersonic for planes at the first level. A patch-up of improvements can bring the 100 tons payload of present design to perhaps 3000 tons payload, sufficient for second-level planes of appropriate productivity.

Fig.3-9a

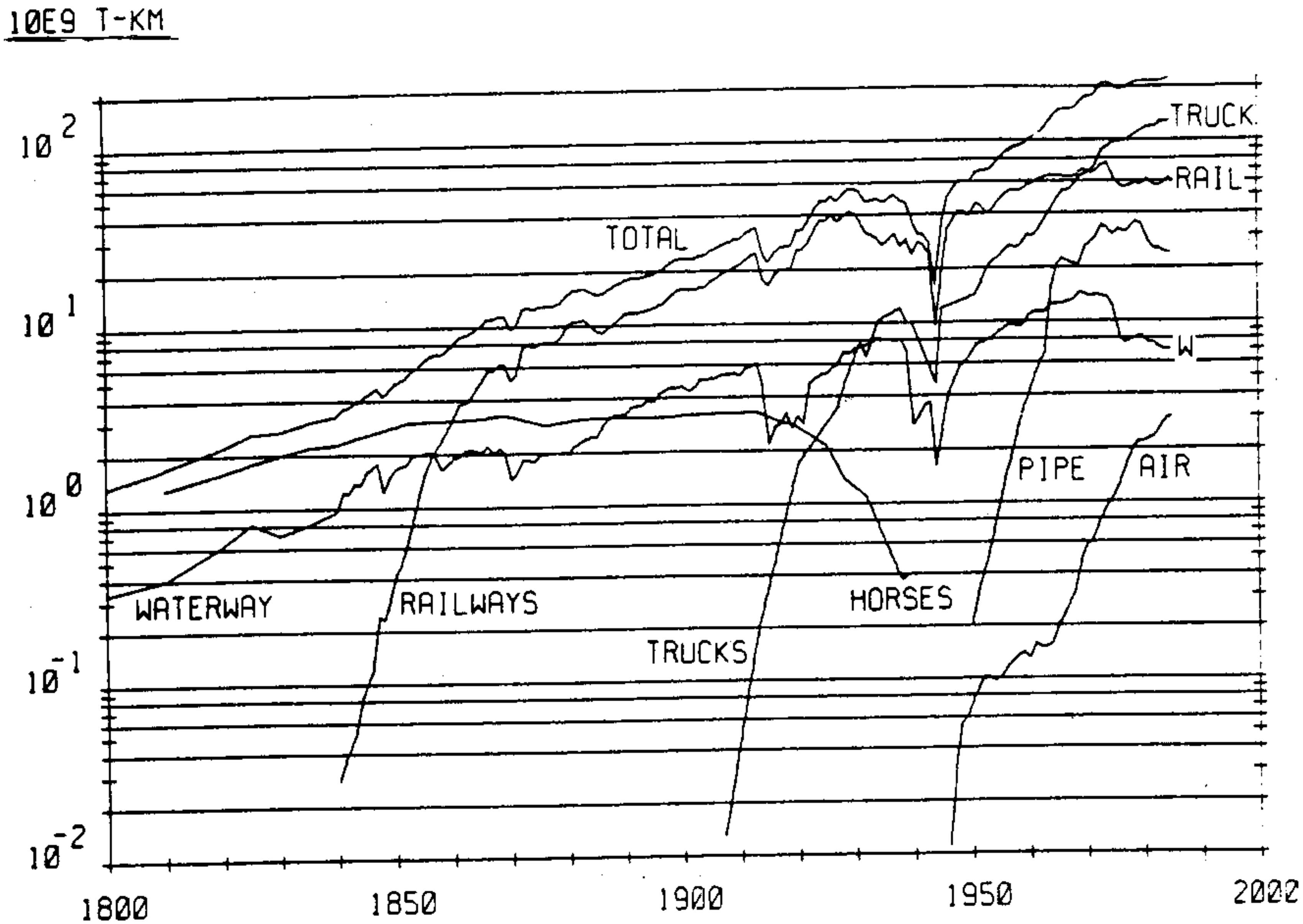

10E9 T-KM
10 2
10 1
10 0
10 -1
10 -2
1800
1850
1900
1950
2000
TOTAL
TRUCK
RAIL
W
WATERWAY
RAILWAYS
TRUCKS
HORSES
PIPE
AIR

Fig.3-8c

USA – Substitution of Transport Infrastructures

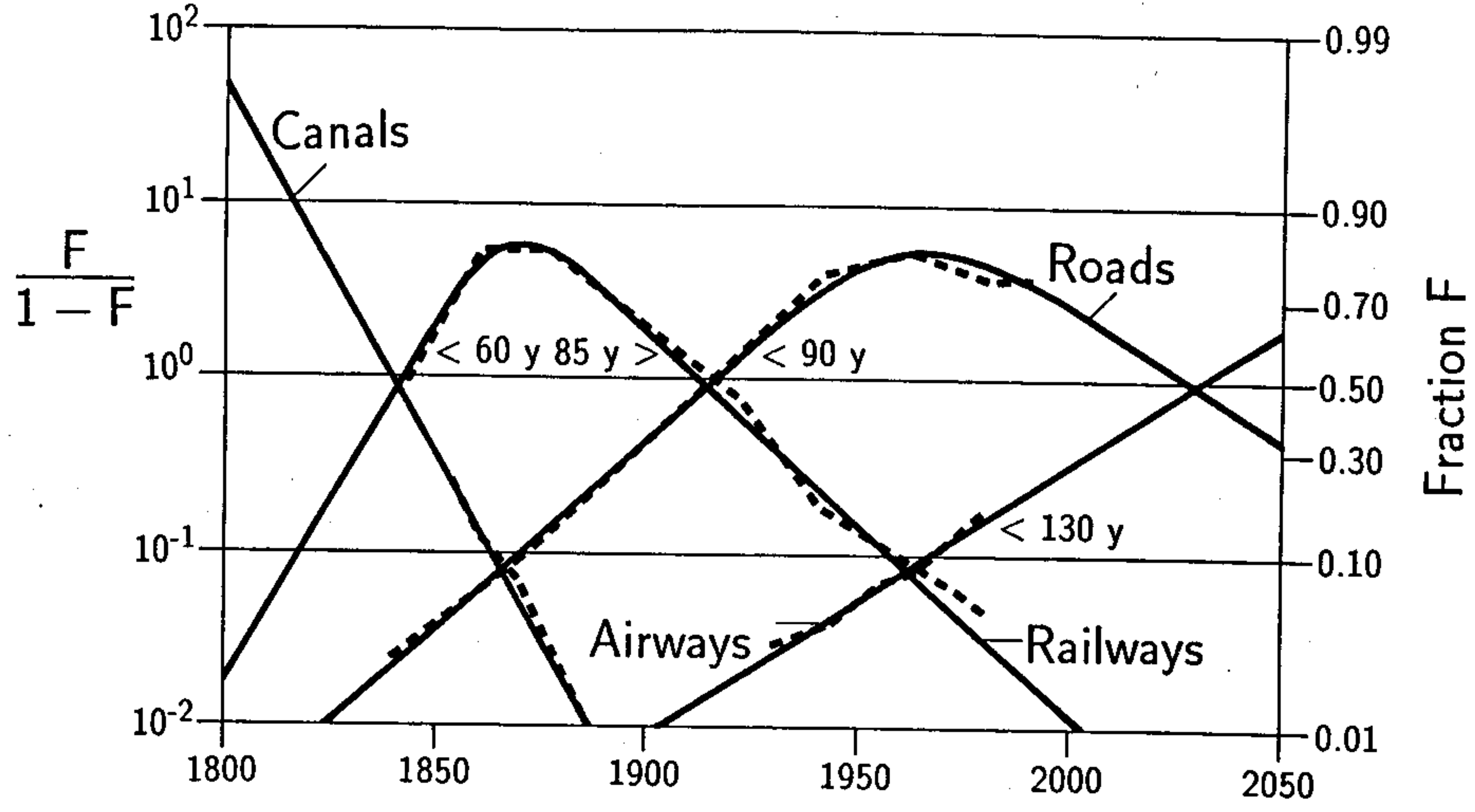


Fig.3-9a,b.

For the transport of goods we can construct a chart like that for the mechanical transport of people of Fig.2-3. Also this one is for France and shows strict taxonomic relationships. We see air transport coming up in two waves, the first one probably referring to mail. For expensive goods air transport is now a must (Fig.3-9b). But air transport is conquering shares on the market of perishable goods of not so high specific value, like fruits, competing with trucks. We may expect planes specially designed for cargo during the next Kondratiev, as the ton-km transport will soon be comparable to that of passengers.

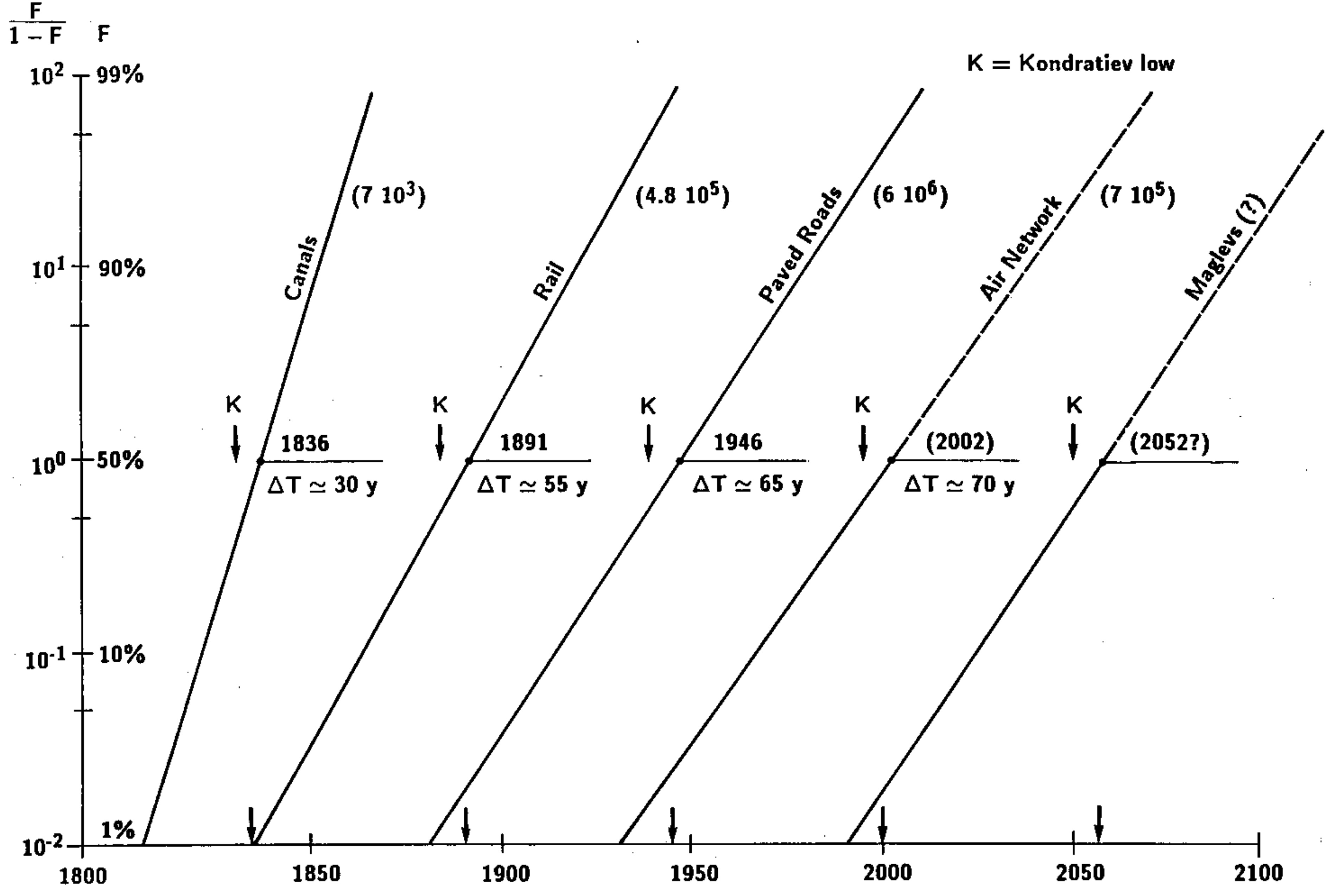


Fig.38a

USA – LENGTH OF TRANSPORT INFRASTRUCTURES (KM)

C. Marchetti, IIASA, 1992

Fig.3-8b

USA – Total Length of infrastructures

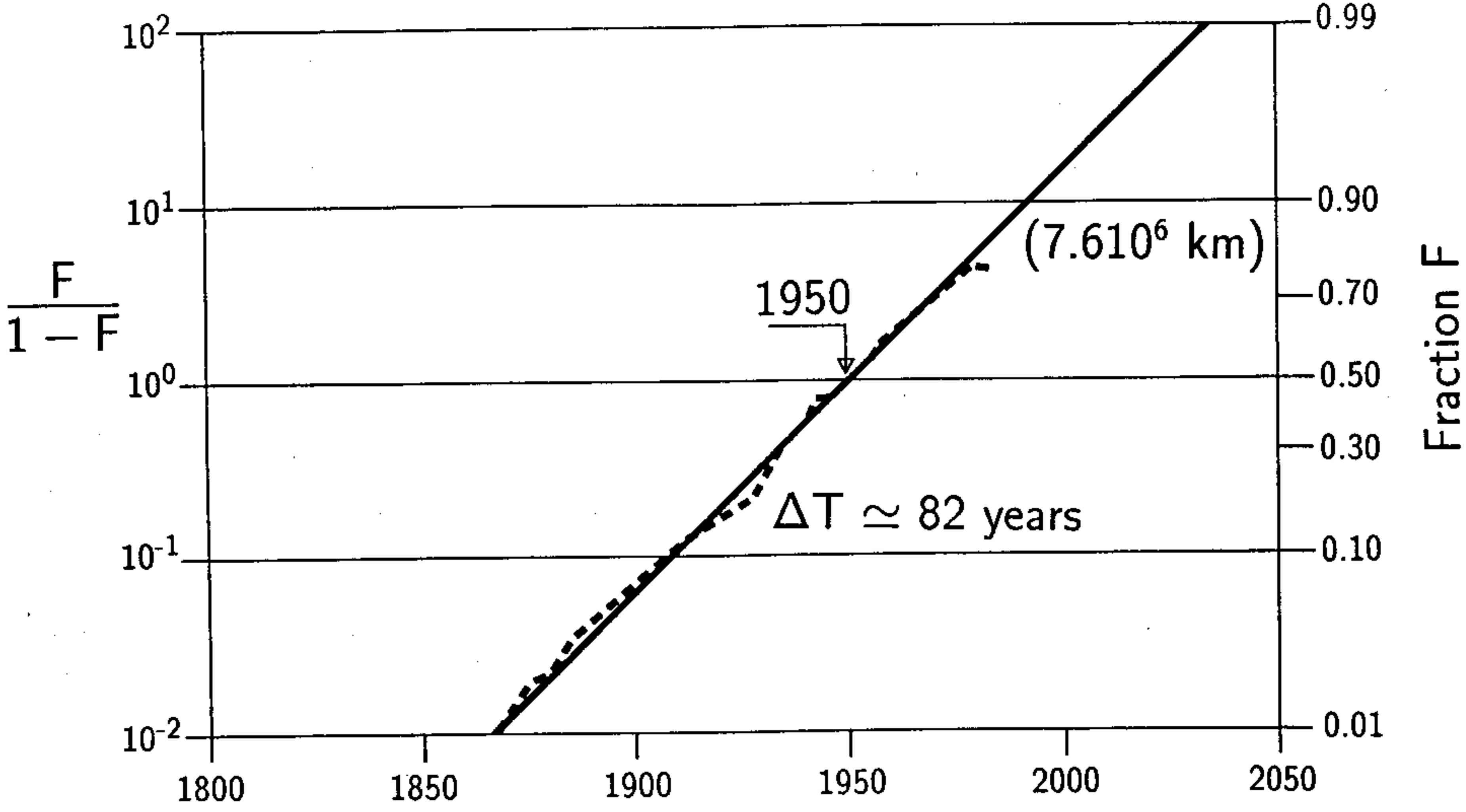
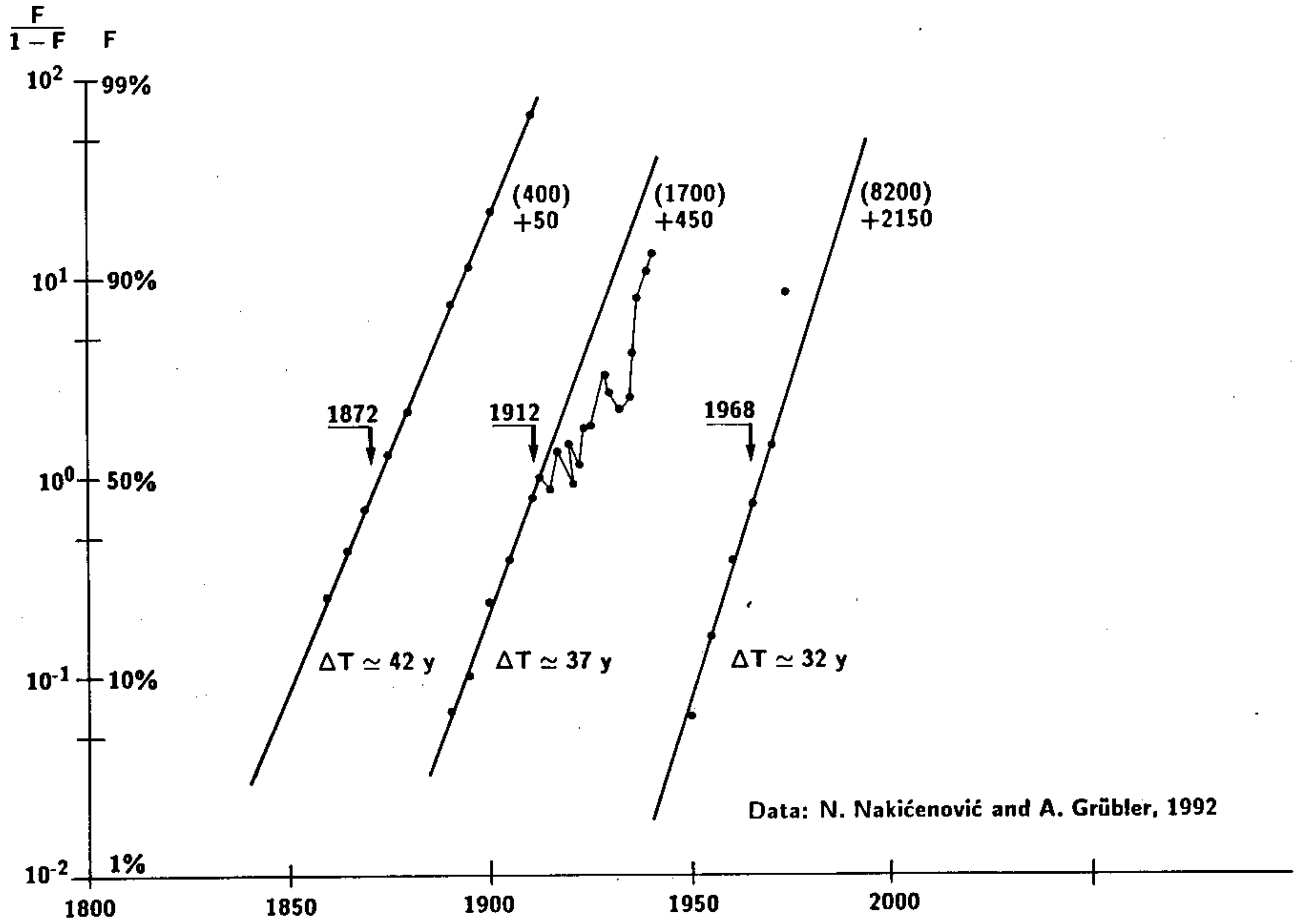


Fig.3-7

WORLD COMMERCIAL ENERGY CONSUMPTION (M-TCE)



Data: N. Nakićenović and A. Grübler, 1992

C. Marchetti, IIASA, 1992

Fig.3-8,b,c.

The penetration of transportation infrastructures of Fig.2-5 can be expressed in terms of the Fisher-Pry transform and expanded to include the air network (the sum of the distance between ticketed points) and a new transport infrastructure, presumably Maglevs. The line for Maglevs is constructed assuming certain taxonomic constraints extracted from the analysis of previous pulses. There is an obvious similarity between Fig.3-7 and Fig.3-8. Both refer to market penetration of new technologies

Fig.3-6

World – All t-km Transported
(Pass = 90 kg)

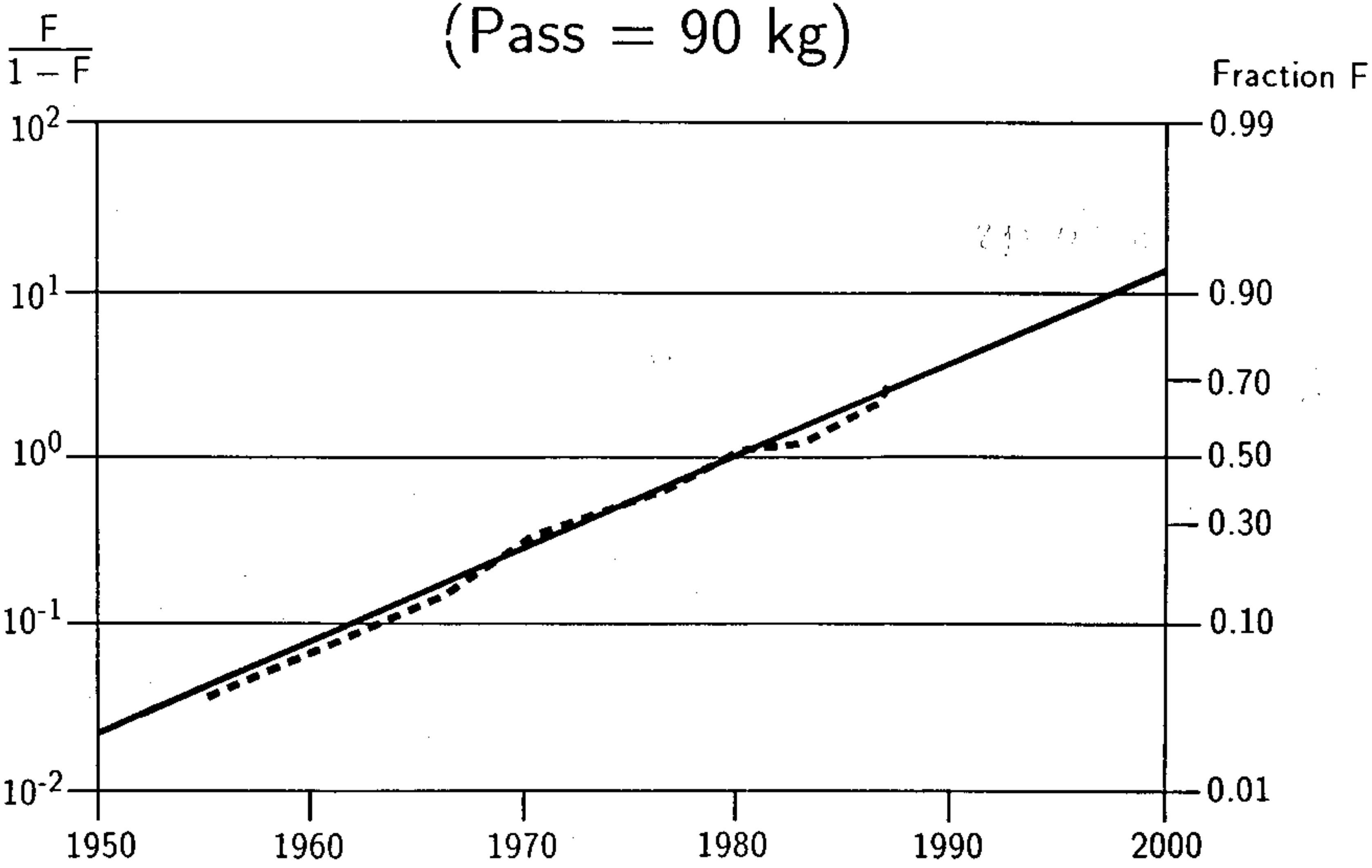


Fig.3-7.

Energy consumption enjoys good statistics, being such an important parameter in the working of Western societies. We took advantage for plotting it since 1850 in terms of three growth pulses. They are in good synchronization with Kondratiev. The deviations of the second can be attributed to the warlike situation in the period between World War I and World War II. Historians now put them together into a 30-year war.

Fig.3-5

Center of Invention and Innovation Waves Located on Energy Indicator

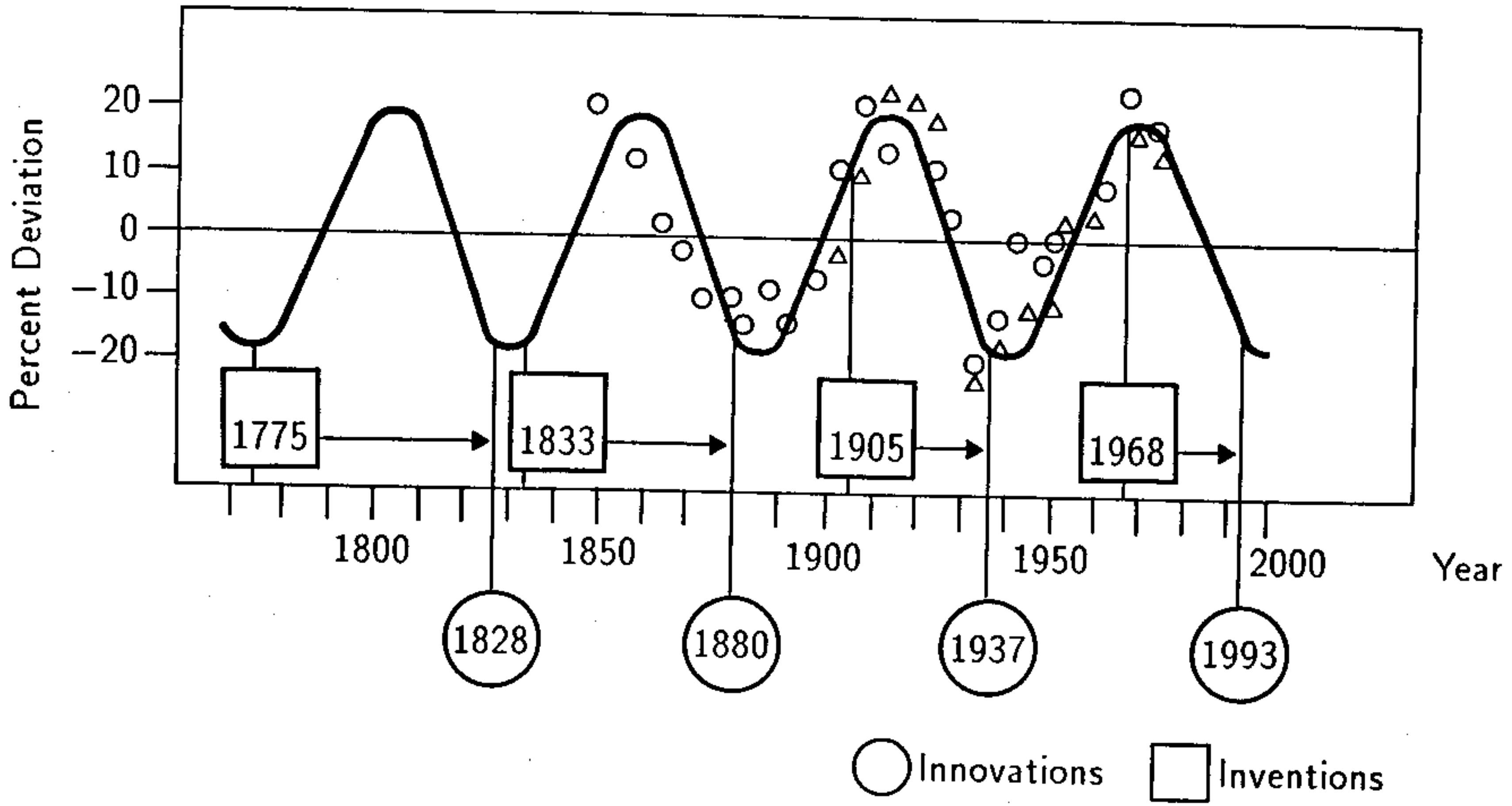


Fig.3-6.

All ton-km transported by the air system including the Soviet Union can be well approximated by a logistic equation from 1955 to 1985. This logistic would saturate at about 300 10^9 ton-km (passengers are counted at 90 kg including baggage). During the last few years, however, a new logistic appears saturating at about 30% of the old one, more or less at the same time. These "second pulses" inside a Kondratiev are possible and they saturate at the same time as the first pulse. They may testify the rapid opening up of a new niche (e.g., charter). In this case we did not search yet for a definition of a new niche (it could also be a transient to be reabsorbed later on).

Fig.3-4

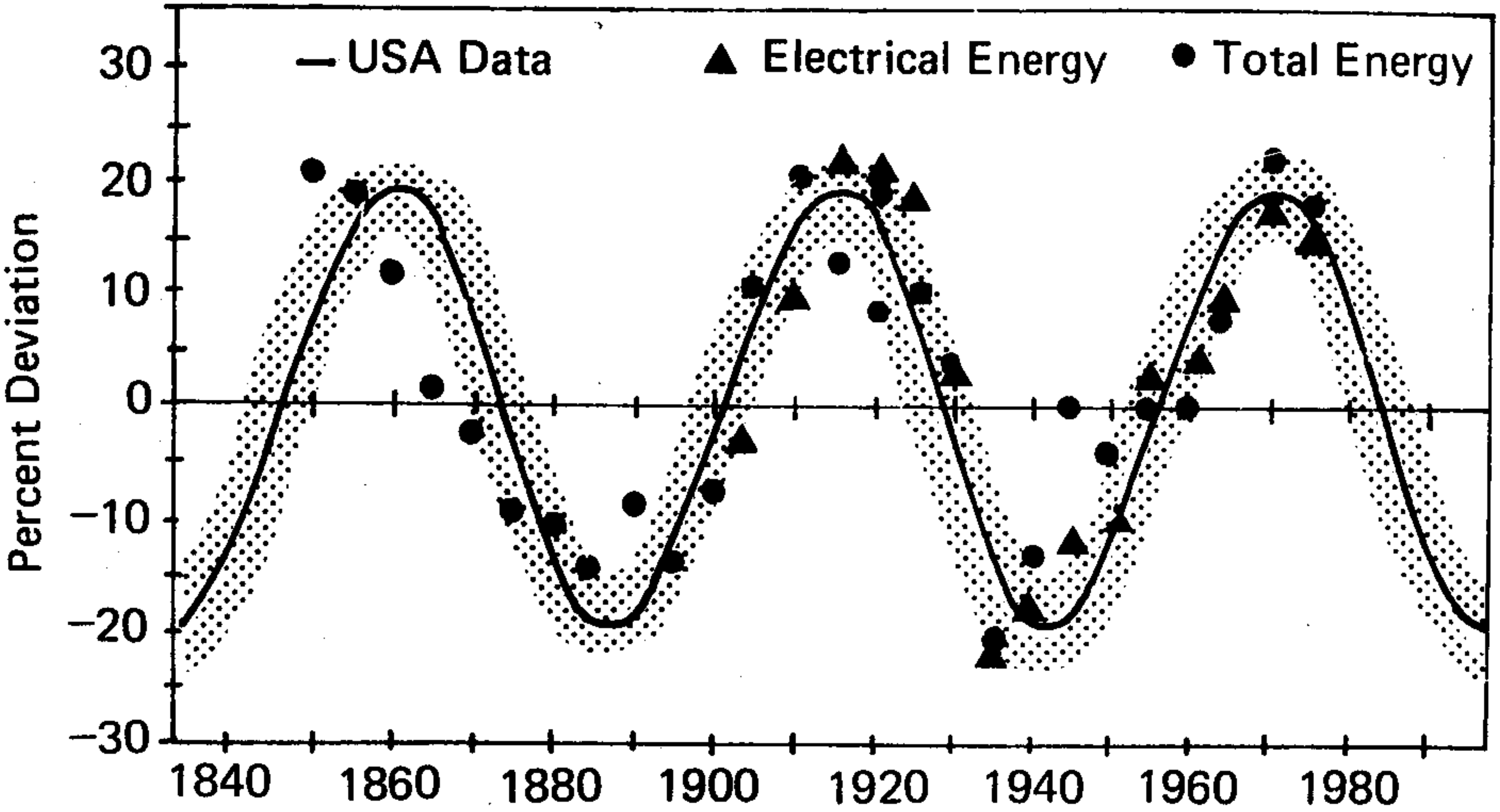
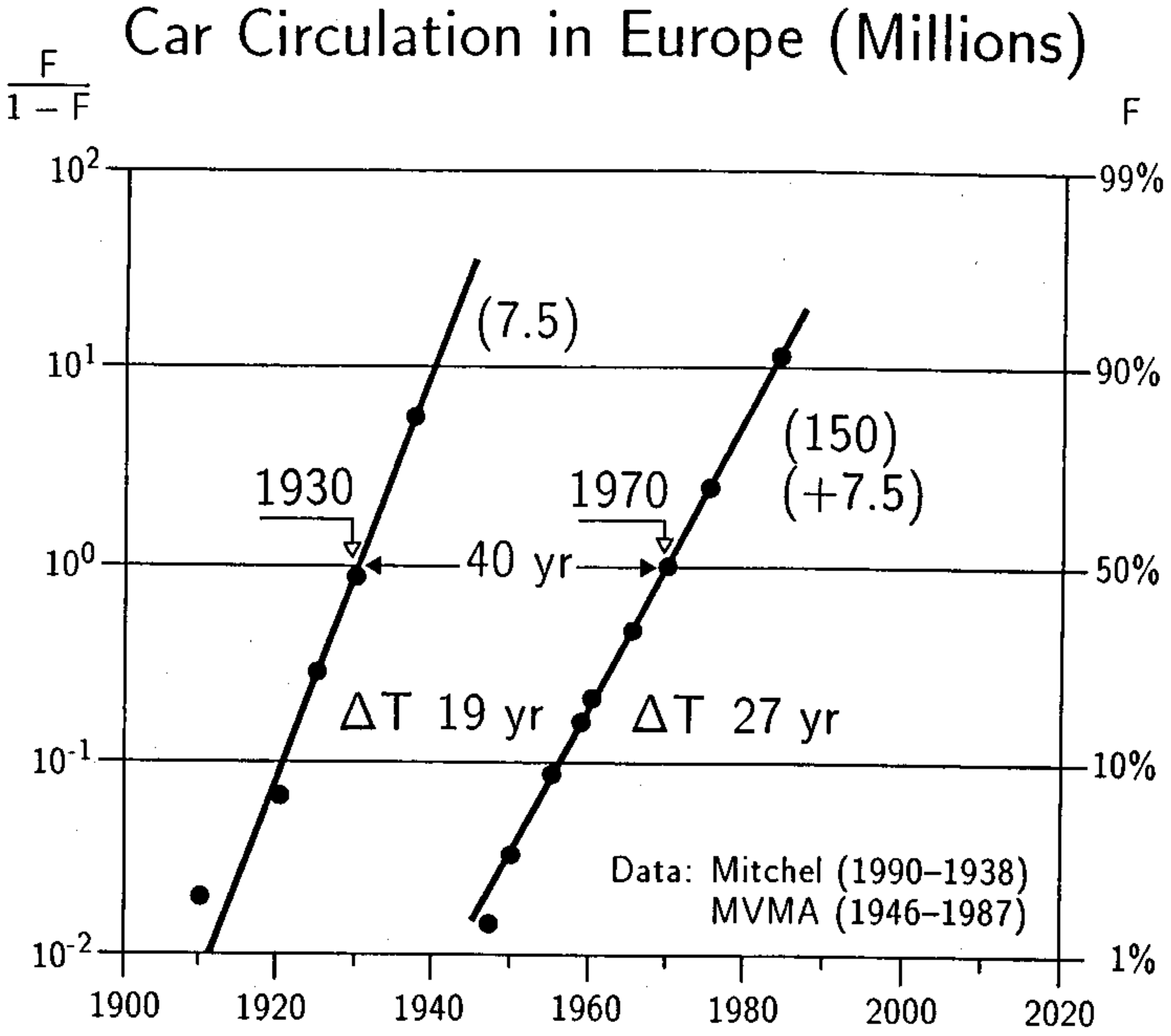

—USA Data
▲ Electrical Energy
● Total Energy
Percent Deviation
30
20
10
0
−10
−20
−30
1840
1860
1880
1900
1920
1940
1960
1980

Fig.3-5.

If we position on this cycle the centers of the innovation waves of Fig.3-1, we find that they are always precisely located a little before the lower end of the cycle (1993 of the present innovation wave). The message is that if we want to introduce innovations in the transport industry in general, and in air transport in particular, *the time is now.*

Fig.3-3



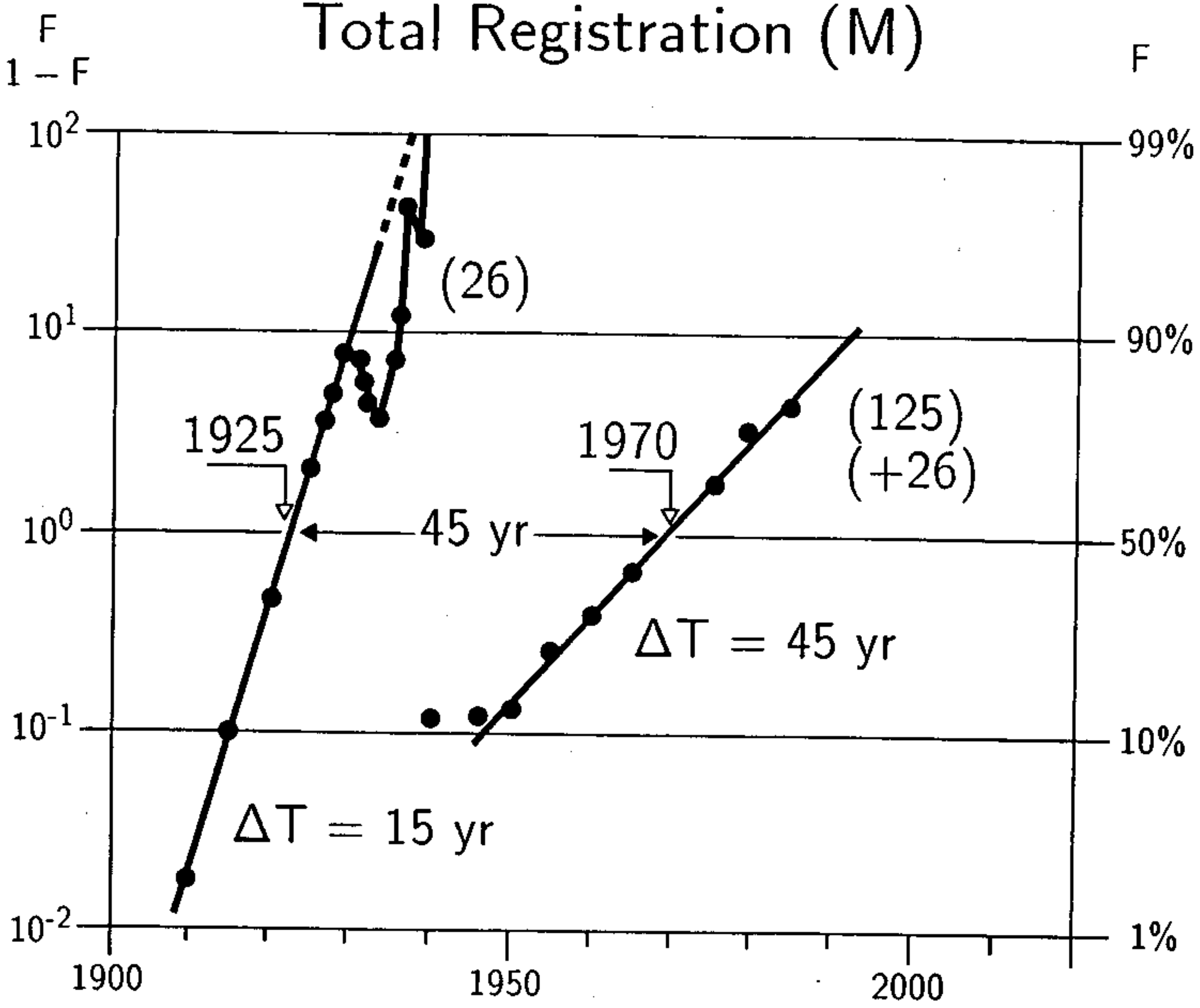
Car Circulation in Europe (Millions)

Fig.3-4.

Stewart observed that the growth of primary energy and of electricity for the USA can be approximated by exponentials. The deviations from these long-term trends can be represented as a sinusoid with a period of about 55 years. The open circles represent total energy and the triangles electricity.

Fig.3-2

USA – Passenger Cars
Total Registration (M)



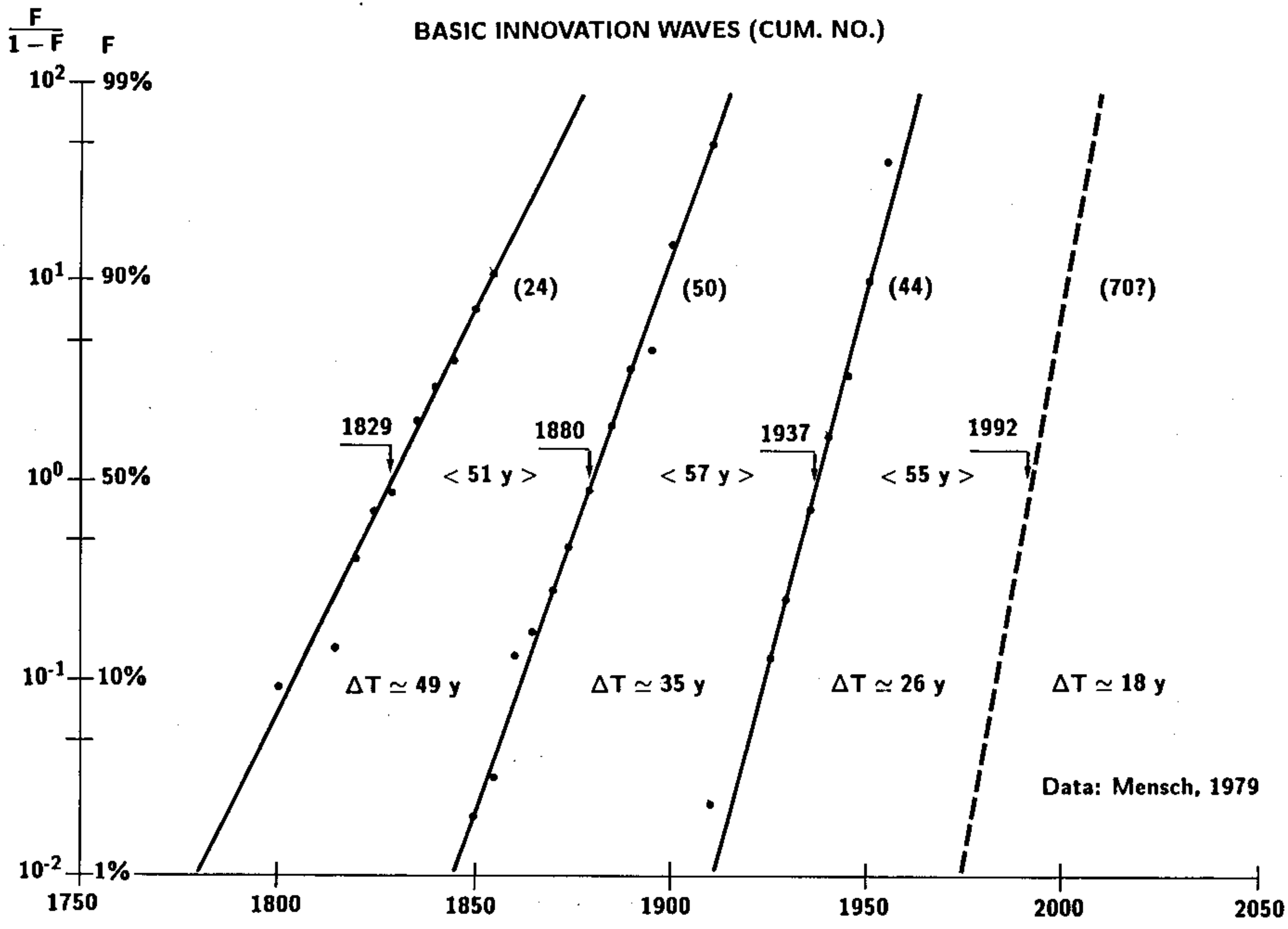
Data: US Historical Statistics & MVMA Statistics, 1987

Fig.3-3.

An innovation does not saturate its markets in a single Kondratiev cycle. We have here the case of cars penetrating in two cycles both in the case of the USA and of Europe. The saturation points are in both cases near the end of Kondratiev cycles (1940, 1995).

Fig.3-1

BASIC INNOVATION WAVES (CUM. NO.)



Data: Mensch, 1979

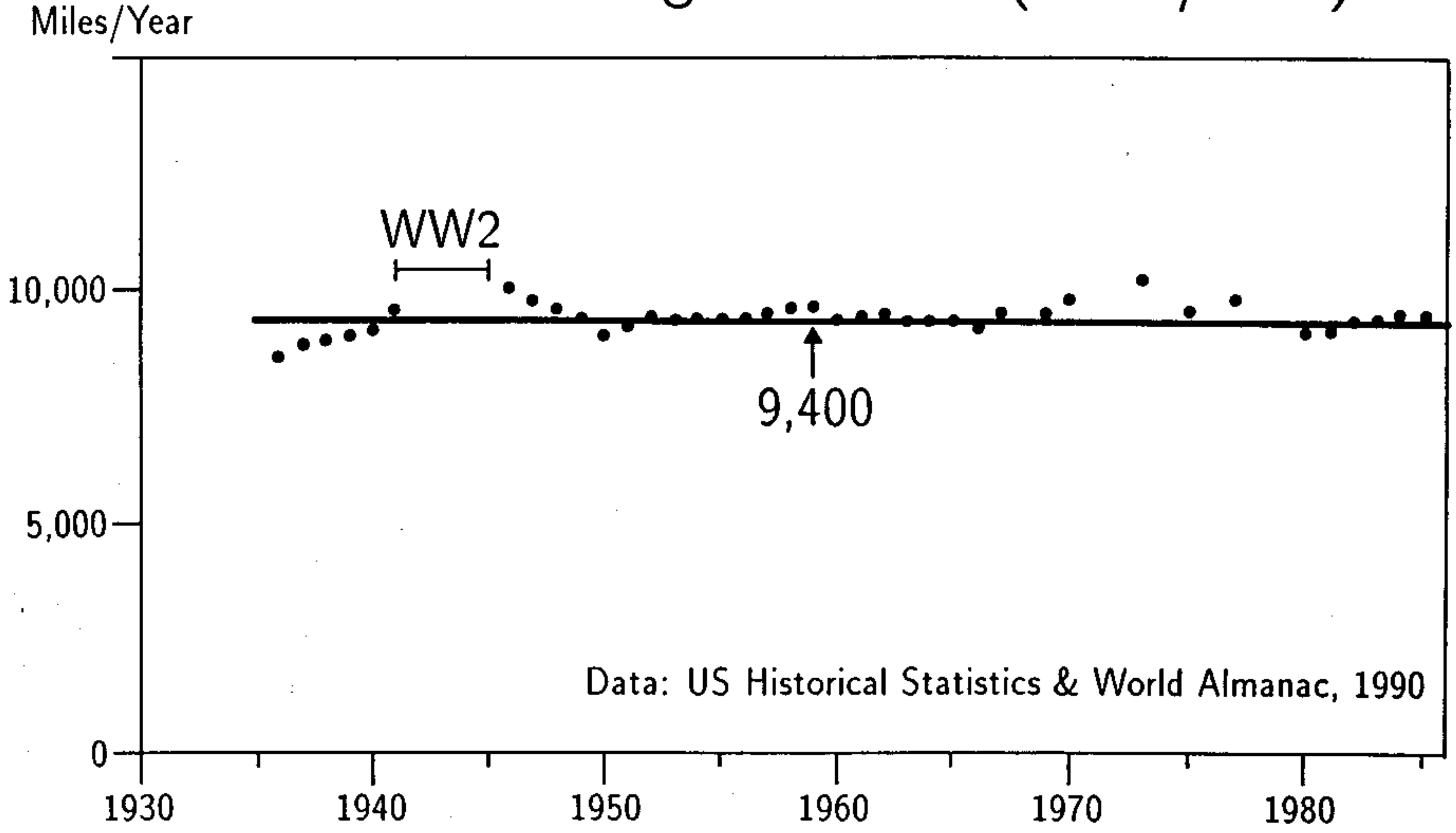
C. Marchetti, IIASA,

Fig.3-2.

An innovation does not saturate its markets in a single Kondratiev cycle. We have here the case of cars penetrating in two cycles both in the case of the USA and of Europe. The saturation points are in both cases near the end of Kondratiev cycles (1940, 1995).

Fig.2-7

USA – Passenger Vehicles (Miles/Year)



Data: US Historical Statistics & World Almanac, 1990

Fig.3-1.

Schumpeter observed that technological innovations come in bunches spaced about 55 years. Mensch put together the bunches by dating the innovations. We showed that the bunches are almost perfectly organized by fitting them with logistic equations. The exercise is reported here, and confirms beyond doubt the intuition of Schumpeter. New technologies for transport are also innovations, and each wave carries a new transport technology. The last one started commercial airplanes. For the present one we assume Maglevs will be the winning technology, starting their penetration in the next century.

Fig.2-6

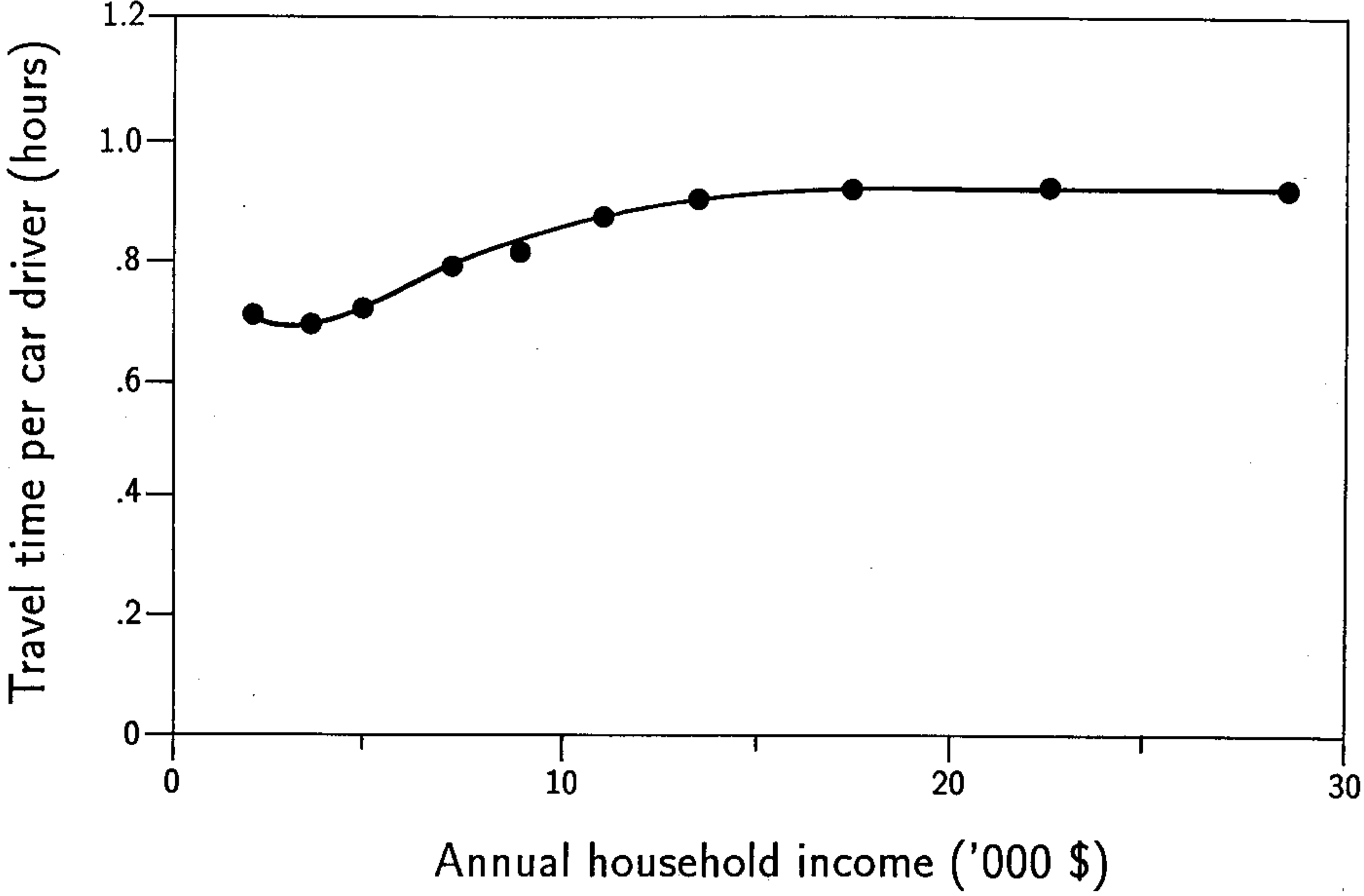
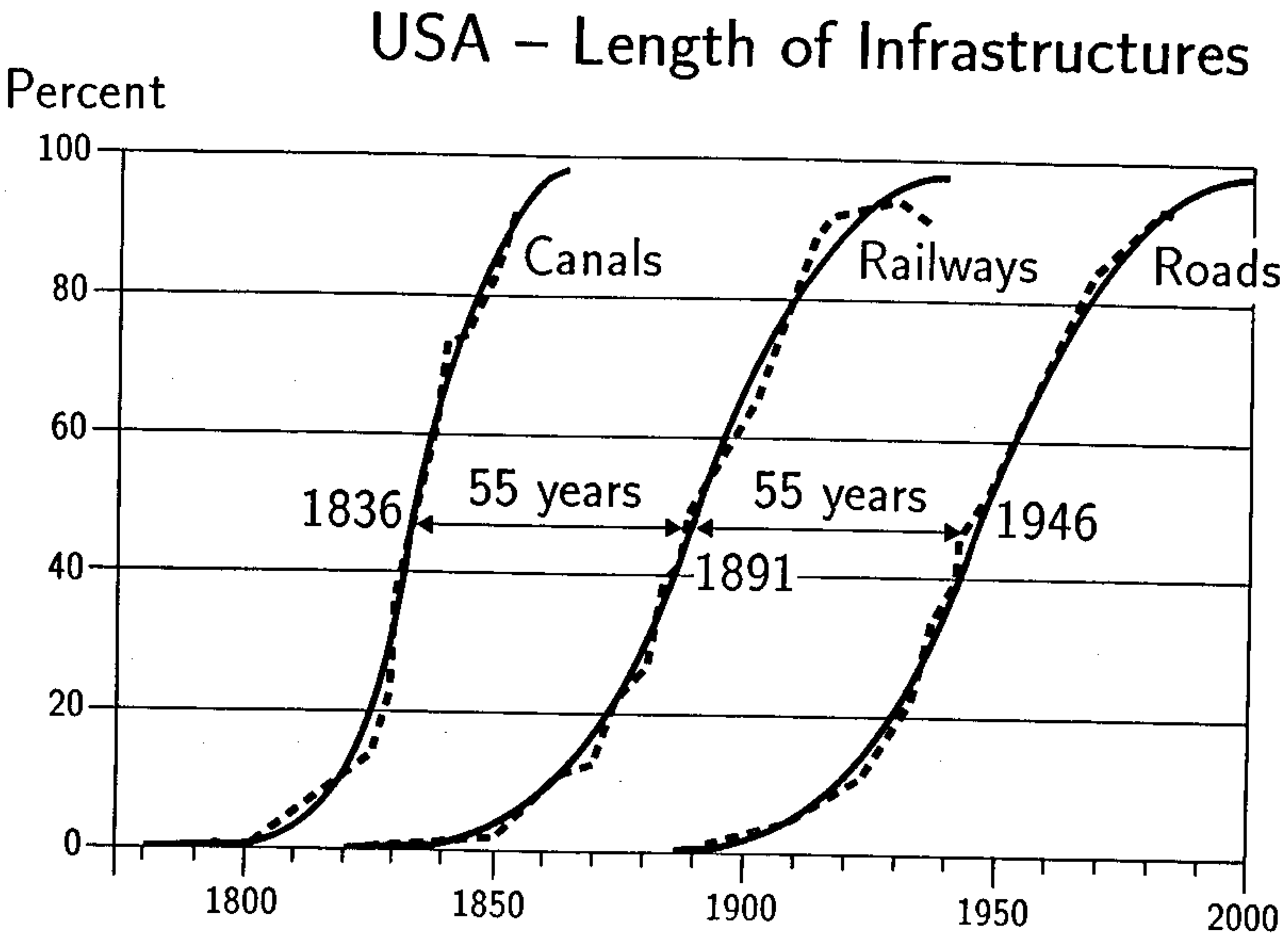

Travel time per car driver (hours)
1.2
1.0
.8
.6
.4
.2
0
0
10
20
30
Annual household income ('000 $)

Fig.2-7.

Because cars are used basically one hour per day, mileage traveled over the year divided by 365 gives the mean speed. This mean speed of about 40 km/h is remarkably constant since Ford's times. This is also the diameter of Berlin. We did not find any plausible mechanism to interpret why all innovations in the mechanics of cars just compensated the hindrances created by their crowding. No more, no less.

Fig.2-5



USA – Length of Infrastructures

Fig.2-6.

When a person can dispose of a car, most of his traveling hour will be spent driving. Cars are the fastest means of transport with the exception of the airplane. Operating costs of care are acceptable into the TMB of a large stratum of family incomes. Airplanes are decidedly too expensive, particularly in Europe. A round trip Vienna–Rome to give an example, costs the equivalent of one month worker's salary, for two flights of roughly one hour each. The $ for the household income in the chart are 1968$.

Fig.2-4b

USA – Share of Intercity Pass–km Between Modes

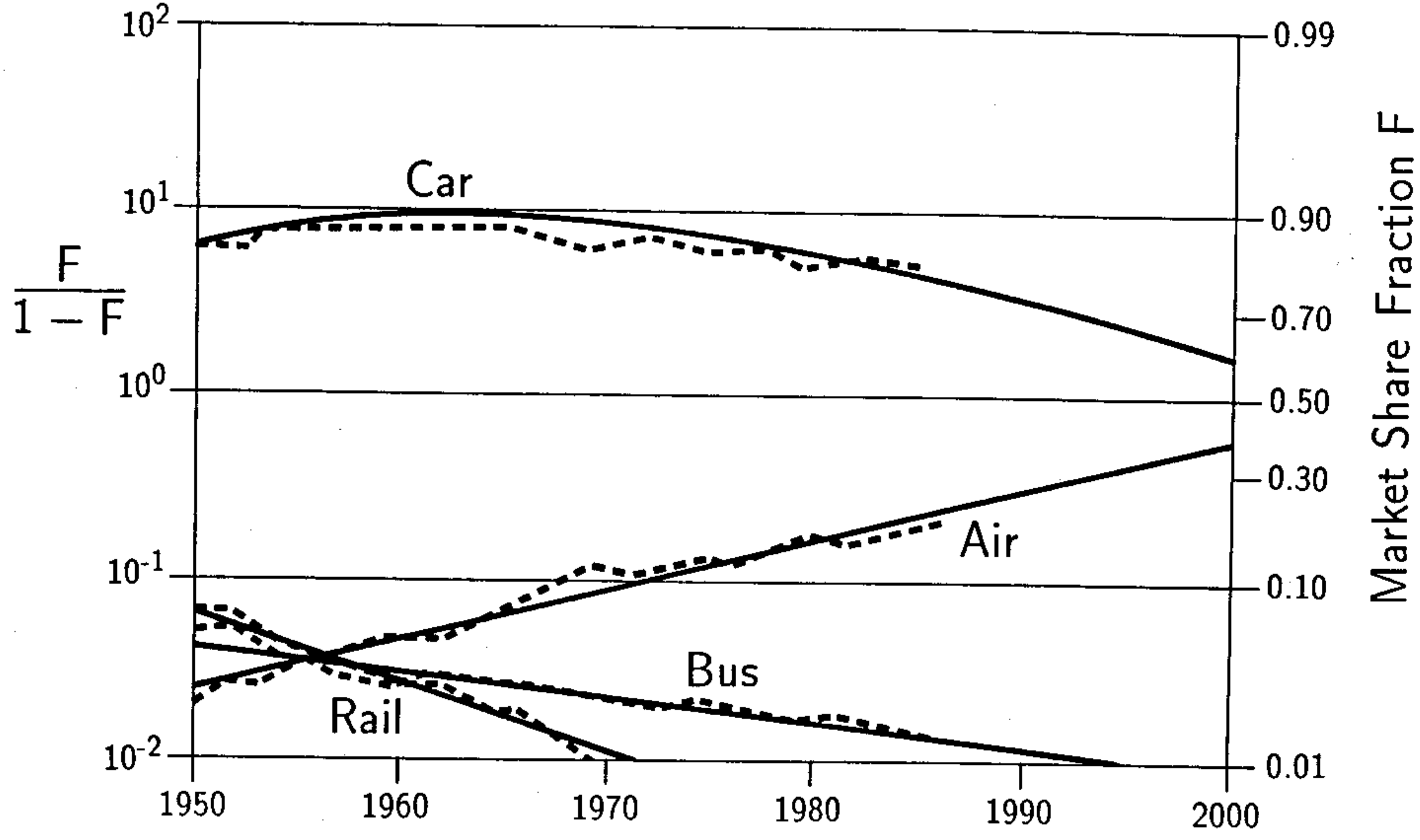


Fig.2-5.

Instead of looking at substitution of vehicles, we can look at the growth of the infrastructures that serve them, as an index of their spatial diffusion into the system. We report here the case of the length of canals, railways, and paved roads referred to their final lengths, and fitted with logistic equations. We note that the flexes of the curves where growth is maximum, are 55 years apart.

Fig.2-4a

UK – Public Passenger Transport Fleet

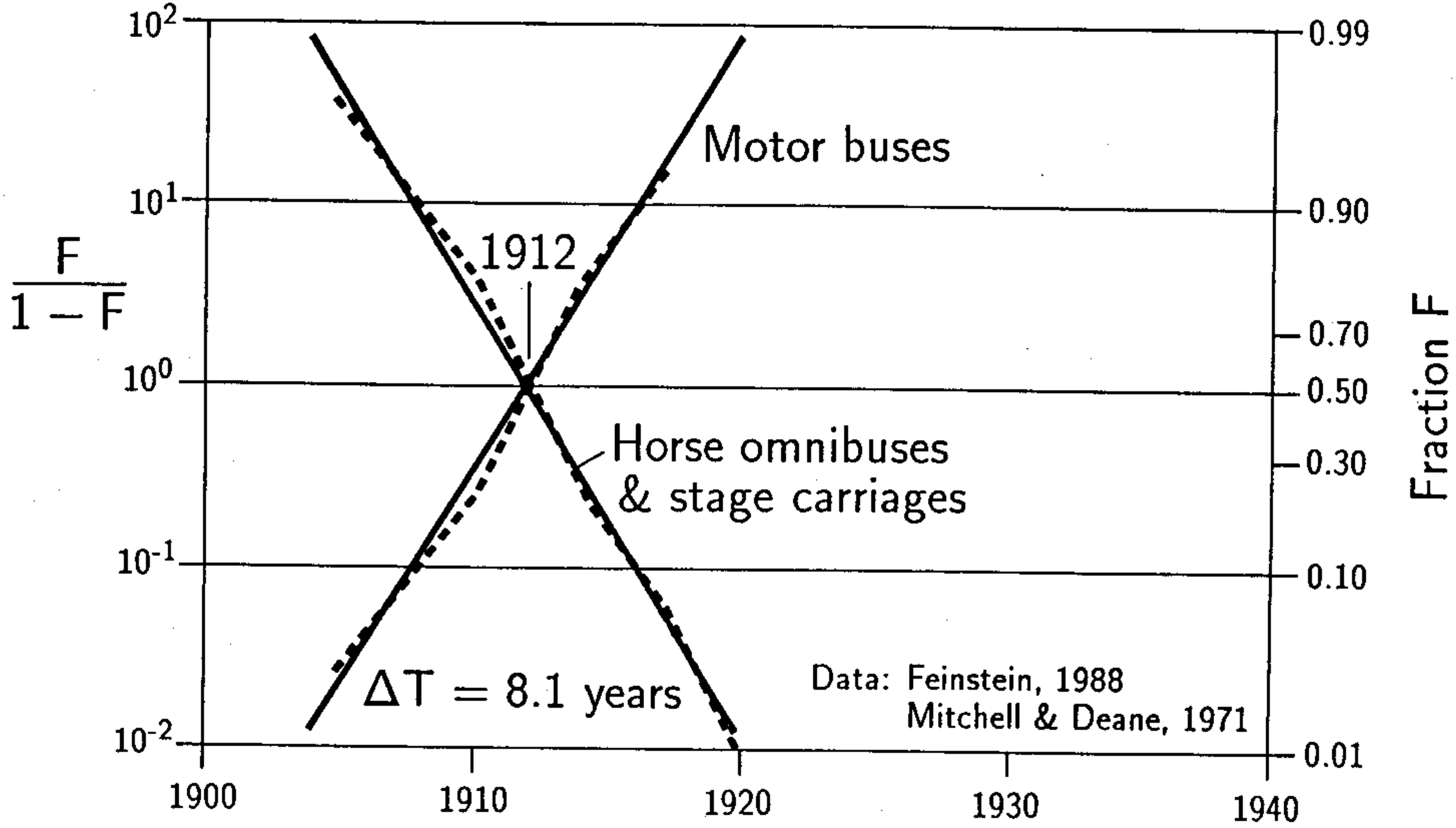


Fig.2-4b.

With the same analytical tools but slightly more complex mathematics we can look at the multiple competition between different modes of transport in the area of intercity travel. This is for the USA. Air mileage should equal car around 2005. Bus and rail are already out of competition.

Fig.2-3

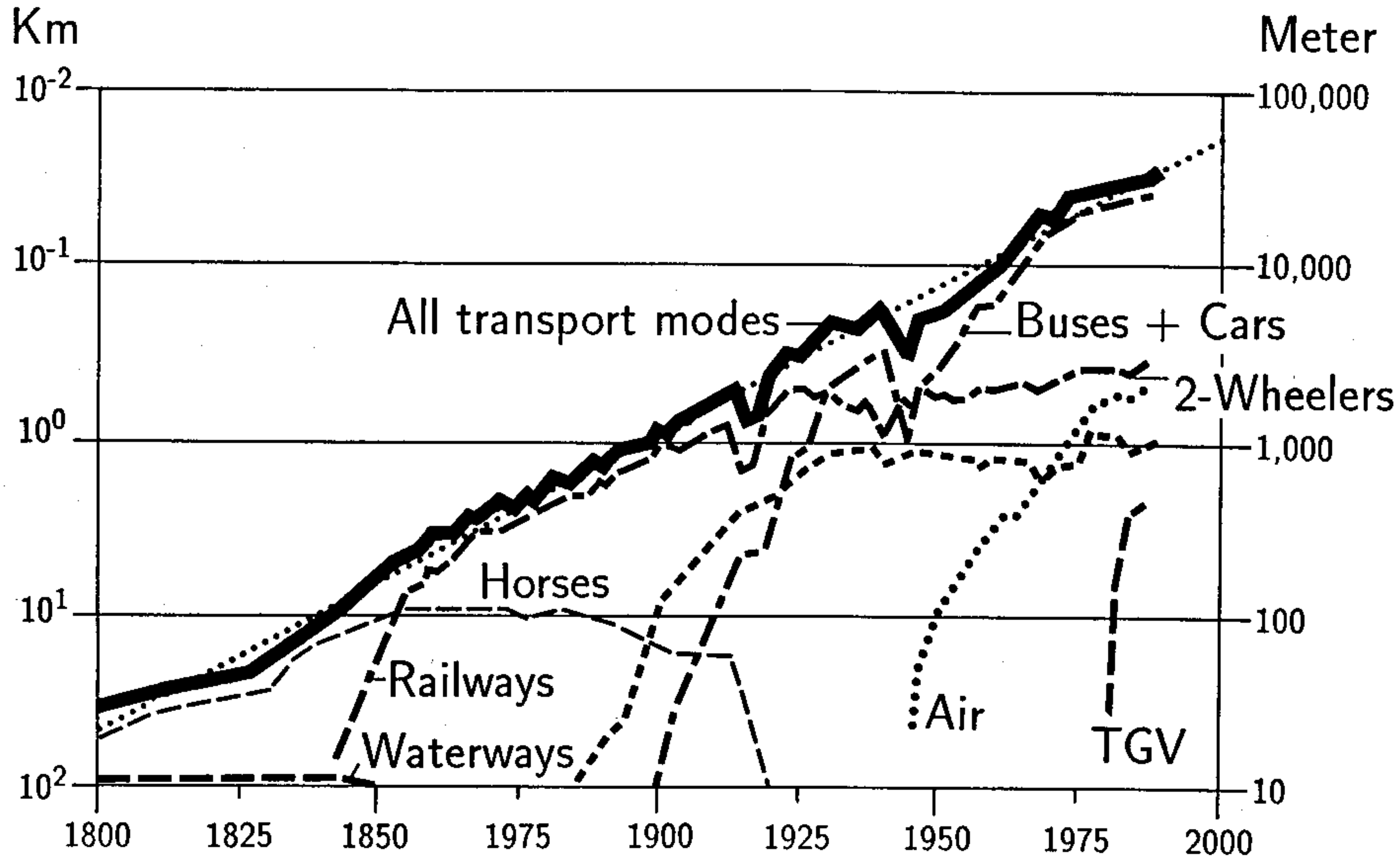

Km
Meter
10-2
10-1
10^0
10^1
10^2
100,000
10,000
1,000
100
10
1800
1825
1850
1975
1900
1925
1950
1975
2000
All transport modes
Buses + Cars
2-Wheelers
Horses
Railways
Waterways
Air
TGV

Fig.2-4a.

The global picture of Fig.2-3 can be split into a number of local phenomena. Reported here is the case of the substitution of horse-driven vehicles with motor-driven vehicles, for public transport in the UK. The complete process of substitution took about 16 years. $\Delta T=8.1$ years refers to the time to go from 10% substitution to 90% substitution.

Fig.2-2

Wachstum einer Großstadt (Berlin)

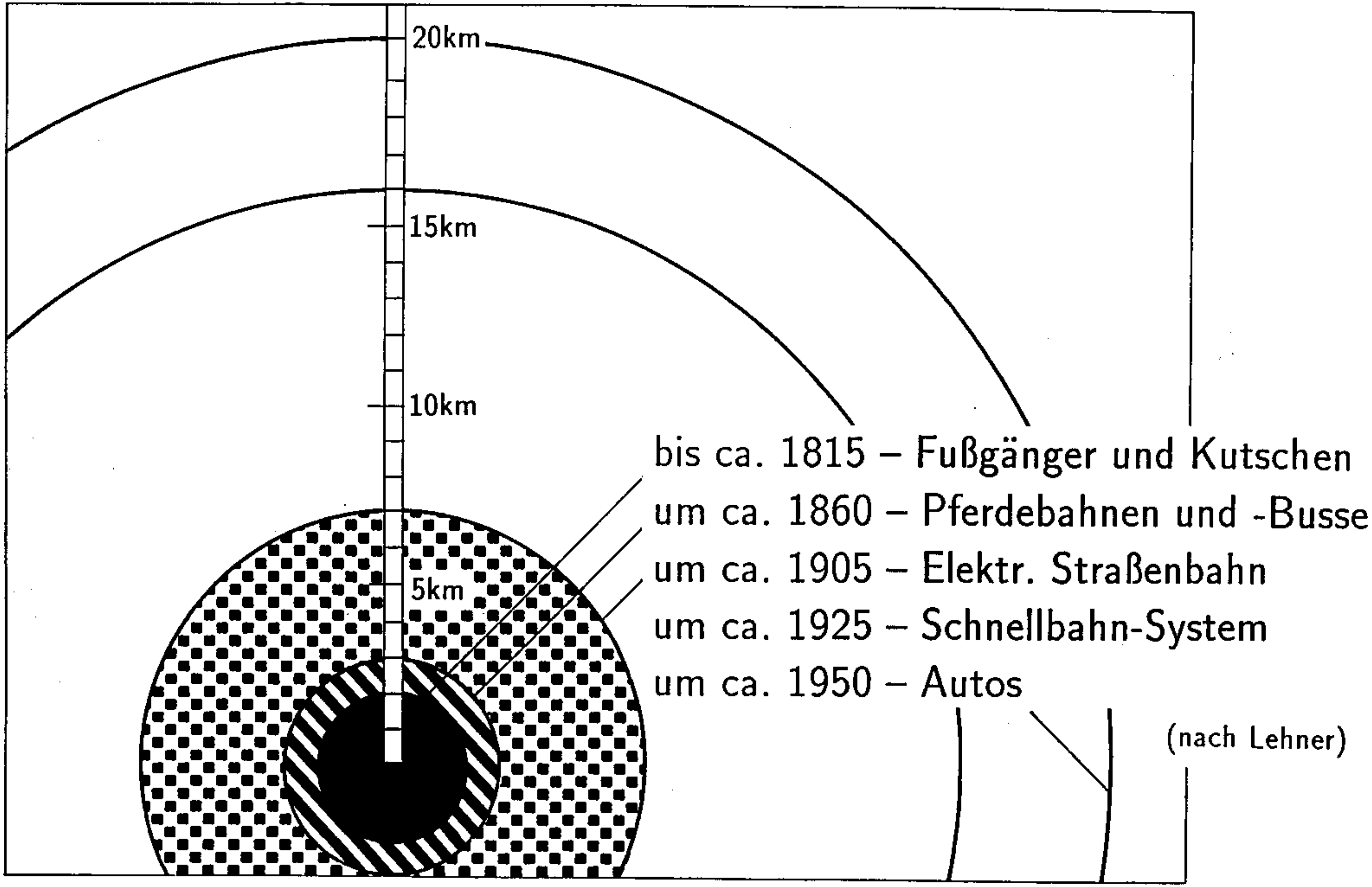


Fig.2-3.

The penetration of mechanical transport, measured in terms of km/person/day is reported here for France since 1800. The introduction of a new technology first stops the growth of the previous one (train versus horse) absorbing all the growth in mileage, then phases it out. The introduction of new transport technologies has a rate of about 55 years. For the next Kondratiev due to start around 1995, a new technology could be that of the Magnetically Levitated Train (Maglev). The total distance traveled with mechanical transport grew in France by about 3.3% per year.

Fig.2-1b

Commuting Fields of Eleven American Cities

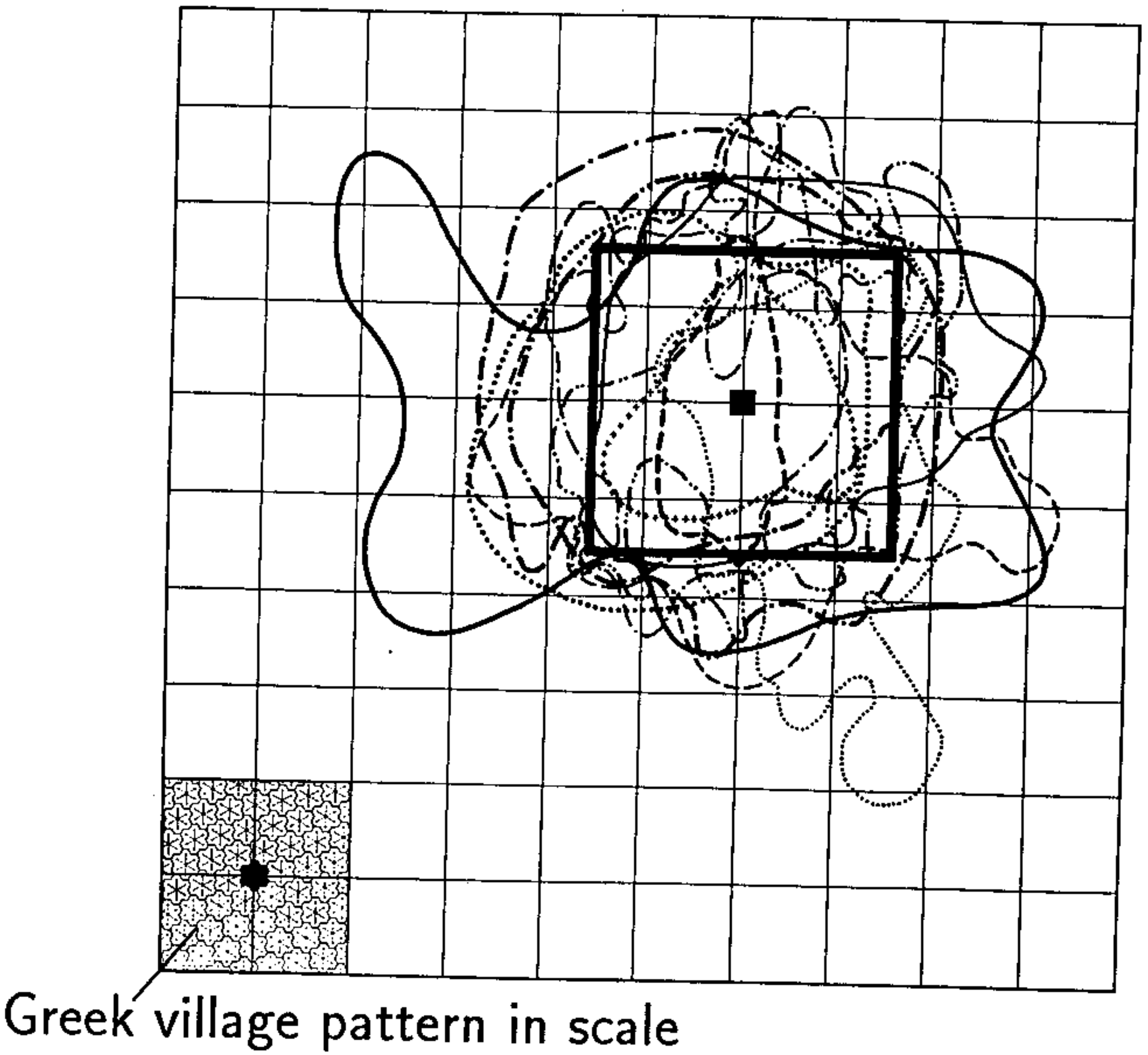
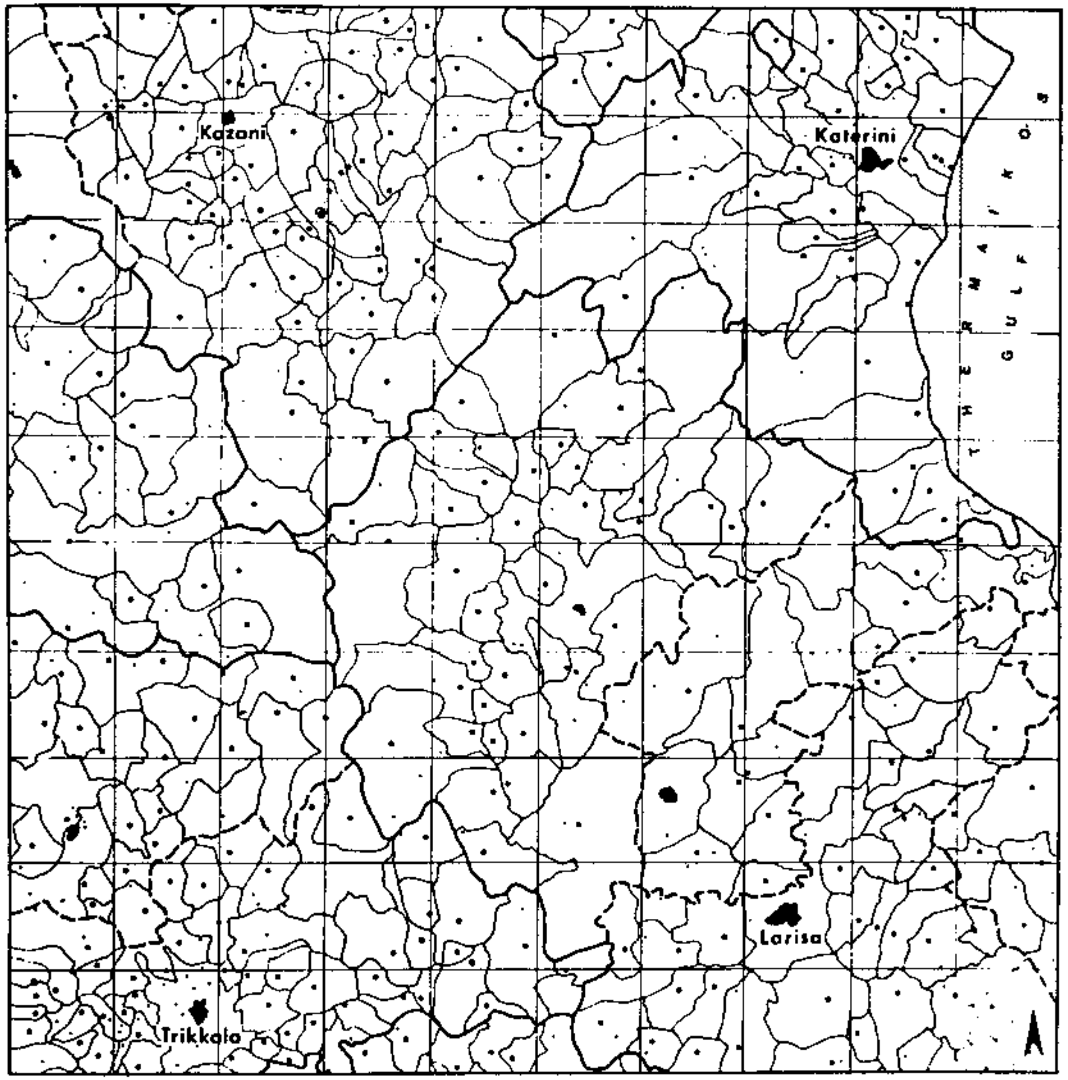


Fig.2-2.

A similar observation as in Fig.2-1 is that large ancient walled cities never grew beyond a diameter of 5 km. Even Berlin in 1900 was a city on foot with a diameter of 5 km. Introducing transport machines expanded city dimensions in close correspondence with the speed of the machines. Berlin with automobiles has reached a diameter of about 40 km.

Fig.2-1a

Village Patterns in Greece



Mean area 22 km^2

Picture Credit

C. Marchetti
Figures: 2-7, 3-1, 3-2, 3-3, 3-5, 3-7, 3-8a

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Fig.2-1a,b.

The fact that transport speed determines special patterns of movements and territories of influence is clearly shown by the dimensions of village territories in Greece, settled when walking was the basic means of transport (at 5 km/h). They have a mean diameter of about 5 km and a mean area of about 20 km^2. If we look at a society operating cars, the commuting patterns have a diameter of about 40 km.