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4. The radar data are relatively insensitive to the values of the "out-of-plane" orbital parameters, which can therefore be fixed in accord with the results from optical observations of the planets without the concomitant errors introducing a significant distortion into the altitude determinations. A detailed description of the methods used to obtain the estimates of the other parameters can be found in M. E. Ash, I. I. Shapiro, W. B. Smith, *Astron. J.* **72**, 338 (1967). See also I. I. Shapiro, M. E. Ash, R. P. Ingalls, W. B. Smith, D. B. Campbell, R. B. Dyce, R. F. Jurgens, G. H Pettengill, *Phys. Rev. Lett.* **26**, 1132 (1971).
5. Another technique, currently being tested, involves the use of only data corresponding to longtitude-latitude resolution cells that were observed from widely separated orbital positions. By the addition of one radius parameter for each such cell, the separation of orbital and topographic effects can be achieved. With the orbits thus obtained, all of the data can be interpreted directly in terms of surface heights. Difficulties with this approach include the effects of (i) omission of a large fraction of the data in the orbit-determination process and (ii) differences in the exact subearth point for data assigned to the same resolution cell.
6. In fact, in some of the computer experiments a parameter representing the "bias" of the Arecibo data relative to Haystack's was added; the estimate for this parameter was always under 1 μsec, which is equivalent to a bias in radius of under 150 m.
7. M. E. Ash, D. B. Campbell, R. B. Dyce, R. P. Ingalls, R. Jurgens, G H. Pettengill, I. I. Shapiro, M. A. Slade, W. B. Smith, T. W. Thompson, *Science* **160**, 985 (1968).
8. At its last general assembly in 1970, the IAU proposed a standard value for the rotation vector of Venus that is consistent with current knowledge. The precise definition is given in *Proceedings of the 14th General Assembly of the International Astronomical Union* (Reidel, Dordrecht, 1971), p. 128. The central meridian on Venus, as seen from the center of the earth at 0 hour, universal time, on 20 June 1964, is 320° in this system and increases with time. The assumed inertial spin period is 243.0 days (retrograde), which is slightly less than the synchronous period of 243.16 days. Partly because of this difference, the data in Fig. 1 are not plotted in exact accord with the IAU system; they are displaced toward smaller longitudes, but nowhere by more than a few degrees.
9. The number of orbital degrees of freedom is not overwhelmingly large. For Venus, only the four in-plane parameters are relevant [see (*4*)]; for the earth, the corresponding orbital elements are also constrained by the radar observations of Mercury and Mars. Thus, of the 23 parameters involved in the solution, relatively few are more than minimally correlated with the topography estimates. This conclusion is verified by the results from solutions in which topography parameters were estimated explicitly (see text).
10. W. B. Smith, R. P. Ingalls, I. I. Shapiro, M. E. Ash, *Radio Sci.* **5**, 411 (1970).
11. For example, note the modest (1 km) near-equatorial rise at 280° longitude.
12. R. P. Ingalls and L. P. Rainville, in preparation; see also (*10*).
13. I. I. Shapiro, M. A. Slade, A. E. E. Rogers, S. H. Zisk, T. W. Thompson, in preparation.
14. The sensitivity of this radar (R. M. Goldstein, personal communication) is about 50 times that of Arecibo, and of Haystack when the latter is observing Venus. Venus's thick CO_2 atmosphere absorbs Haystack's X-band radiation and thereby reduces the echo power by a factor of about 6 relative to the echoes from the Goldstone and Arecibo signals, which are at substantially lower radio frequencies.
15. F. D. Drake, personal communication.
16. We thank M. E. Ash, R. Cappallo, R. F. Jurgens, and W. B. Smith for their vital contributions to earlier phases of this study and the staffs of the Haystack Observatory and the National Astronomy and Ionosphere Center for their aid in performing the radar experiments. Research at the Haystack Observatory is supported by NSF grant GP-25865 and NASA grant NGR22-174-003; contract NAS9-7830. The National Astronomy and Ionosphere Center is operated by Cornell University under a contract with the National Science Foundation.

20 September 1971

Visibility and Soiling: A Comparison of the Effects of Leaded and Unleaded Gasolines

Abstract. *The emissions from a fleet of late-model cars fueled with commercial, high-aromatic, unleaded gasoline caused nearly twice as much atmospheric light extinction as those from a matched fleet fueled with commercial, low-aromatic, leaded gasoline, when both were driven according to a consumer operating cycle in an idle traffic tunnel. The increased extinction and greater soiling potential result mainly from greater light absorption by the air-suspended particles from the unleaded fleet.*

It has been postulated that atmospheric clarity (*1*) might be improved if unleaded rather than leaded gasoline were used, because the light-scattering particles of lead compounds would be absent from the exhaust (*2*). On the other hand, calculations based on measurements of the mass of aerosol particles emitted from dynamometer-driven cars have shown greater volumes of exhaust particles from unleaded than from leaded gasoline during consumer-type mileage accumulations (*3*), a result which suggests that the use of unleaded fuel could result in reduced, rather than improved, atmospheric visibility. In tests designed to test this inference, the diluted exhaust of dynamometer-driven 1970 cars burning leaded and unleaded versions of two gasoline blends, each having an aromatic content of either 24 or 55 percent (by volume), showed greater light scattering and soiling in the absence of lead additives at the low, as well as the high, aromatic concentration (*4*).

Maintenance of octane quality at levels satisfactory for most cars now on the road, under realistic schedules for the rapid removal of lead antiknock compounds from commercial gasoline, would demand an appreciable increase in the aromatic content of gasoline (*5*). The study reported here was made to determine how atmospheric visibility and soiling might be affected if motorists with pre-1971 cars were forced, by restrictions in the lead content of gasoline, to use unleaded gasoline of necessarily high aromatic content. Under realistic driving conditions, the exhaust aerosol generated by the use of unleaded fuel of predominately high aromatic content caused appreciably greater light absorption and soiling than that from low-aromatic leaded fuel.

An idle, concrete-surfaced traffic tunnel with a straight and approximately level two-lane roadway 2 km long was converted into a controlled environmental test chamber in which cars were driven according to the 7-mode federal test cycle (*6*). The large available working volume (7×10^4 m^3) allowed the attainment of exhaust dilution levels typical of those that occur in urban atmospheres without the uncertainties of proportional sampling. Because of the remote location of the tunnel in the Appalachian Mountains of southern Pennsylvania, freedom from sources of industrial or vehicular pollution provided clean ambient air for flushing the tunnel between tests.

Two four-car fleets (one 1969 model, two 1970 models, and one 1971 model) of matched standard automobiles were used, one fleet burning leaded gasoline and the other fleet burning unleaded gasoline. Companion pairs of cars of the same year, one burning leaded and the other burning unleaded gasoline, had similar histories of operation and mileage on their respective fuel types.

The cars of the leaded fleet were operated on premium fuels of low (25 to 26 percent) aromatic content representative of current commercially available gasoline. The pre-1971 cars of the unleaded fleet were fueled with a commercial premium unleaded gasoline of high (54 percent) aromatic content to satisfy their octane requirements, whereas the 1971 car of the unleaded fleet was satisfactorily operated on an unleaded gasoline with a low (27 percent) aromatic content. Companion cars in the two fleets were adjusted to factory specifications, and gaseous emissions were measured prior to testing. Periodic field checks of tail pipe

CO concentration and of mechanical settings indicated that the cars stayed in adjustment during the tests.

Prior to each test, a conditioning routine was followed which brought the concentration of aerosol particles in the tunnel, as indicated by light-scattering measurements with an integrating nephelometer (7), and the CO concentration, as measured by long-path nondispersive infrared absorption, close to outdoor concentrations; furthermore, the conditioning routine ensured that minimum reentrainment of settled particles would occur to interfere with measurements of light transmission, light scattering, and soiling during driving tests.

In order to simulate motorist driving, emission concentrations were built up in the preconditioned, sealed tunnel by driving (with an audiotape prompter aid) six 7-mode federal test cycles, from a cold start, with each of the four cars of a test fleet, one car at a time. The distance traversed per cycle was approximately 1.35 km of the available 2 km of roadway. This resulted in a total of about 32 km of driving for each test and produced concentrations of exhaust pollutants comparable to those in heavy traffic as determined by measurements of CO concentrations.

The resultant changes in the optical properties of the atmospheric aerosol of the tunnel for seven such tests with each fuel type are summarized in Table 1. The attenuation of a white light source at the starting point of the test car was measured 797 m down the driving course in the dark tunnel by means of a microphotometer with an achromat (5-cm aperture, 13.7-cm focal length) having a pinhole of radius 1.3 mm at the focus to image the source on an S-4 spectral-response photomultiplier tube. The initial aerosol scattering coefficient was routinely measured with a nephelometer at the starting point of the test car after surveys verified the spatial uniformity of the tunnel aerosol at the end of the preliminary conditioning routine. At the conclusion of some driving tests, a continuous horizontal profile of the light scattering coefficient was obtained by means of a nephelometer traverse 2 m above the road along the whole tunnel length.

The average increase in the total light extinction coefficient after the operation of the unleaded fleet was almost twice that observed after the operation of the leaded fleet. Although sufficient experimental data are not available to permit one to partition the increase of extinction into contributions due to the reentrainment of settled particles, particles of oil and tire rubber, and particulate emissions from the tail pipe, the fact that the fleets were matched for history, condition, and operation implies that the observed differences in the light scattering and in the absorption of the diluted vehicular primary aerosol were due mainly to the fuel difference.

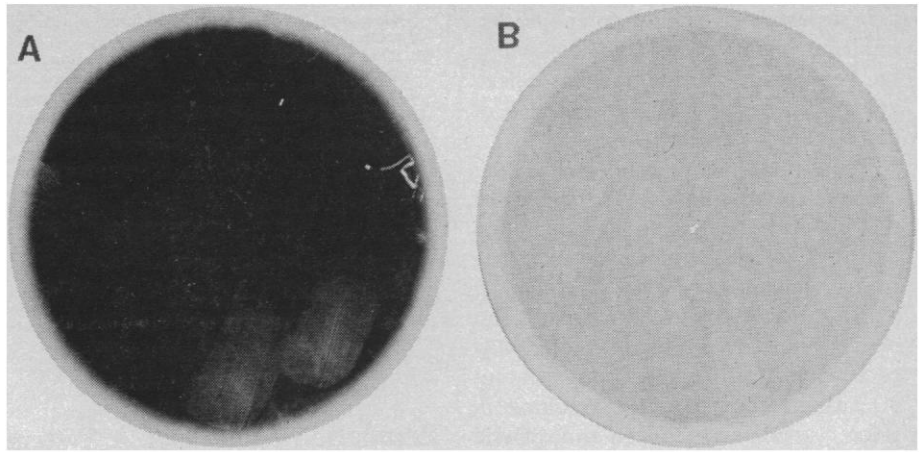

Fig. 1. Filter samples of tunnel atmospheric aerosol from tests on 20 April 1971: (A) unleaded gasoline; (B) leaded gasoline.

Although the mean increase in the light-scattering coefficient was 20 to 63 percent greater for the unleaded than for the leaded fleet, the major contribution to the observed doubling of the extinction coefficient was from the absorption component. The mean increase in the absorption coefficient of the diluted primary aerosol was 100 to 360 percent greater after unleaded- than after leaded-fleet operation. This behavior is consistent both with the sooty appearance (Fig. 1) of filter collections of the vehicular aerosol generated during driving tests with the unleaded fleet and with the known catalytic effect of lead salts on carbon oxidation (8).

Samples of the atmospheric aerosol from the tunnel (exemplified by Fig. 1) were collected for each test 224 m from the starting point along the route, 2 m above the road surface, at curbside, by membrane filtration (diameter, 102 mm; pore size, 0.45 μm; air flow rate, 140 liters per minute) during the driving operation, which took about 1 hour for all 24 cycles. The reflectance of the used filters was measured versus that of an MgO standard at 550 nm by means of a reflectance spectrophotometer. The mean decrease of filter reflectance on the basis of this procedure was 64 percent for the unleaded fleet and 41 percent for the leaded fleet (seven tests for each fleet). This measurement, which may be interpreted

Table 1. Effect of fuel type on aerosol optical properties.

Test date (1971)	Initial scattering coefficient (km^{-1})	Increase in light attenuation component coefficients during test (km^{-1})*		
		Extinction	Scattering	Absorption
		Leaded gasoline		
16 April	0.12	0.27		
20 April	.08	.23		
1 May	.22	.34	0.30	0.04
4 May	.08	.37	0.26	0.11
5 May	.12	.29	>0.24	<0.05
10 June	.09	.35		
11 June	.11	.28	0.16	0.12
Mean	.12	.30	0.24–0.25	0.07–0.08
		Unleaded gasoline		
15 April	0.06	0.57		
20 April	.07	.66		
1 May	.20	.59	0.36	0.23
4 May	.08	.77	>0.41	<0.36
5 May	.12	.62	0.24	0.38
10 June	.09	.39		
11 June	.27	.51	0.19	0.32
Mean	.13	.59	0.30–0.39	0.23–0.32

* Calculated as outlined in (10).

as a measure of soiling potential (*9*), implies over 50 percent greater soiling by the aerosol of the unleaded fleet, apparently because of the presence of carbonaceous particles.

These field tests, conducted under the maximum practicable degree of realism with respect to car operation and fuel choices, confirm the inference from the laboratory tests of Habibi *et al.* (*3*) that the use of current commercial unleaded fuels in present-day cars would lead to an increased output of carbonaceous particles, resulting in greater soiling and reduced atmospheric clarity. The observed near-doubling of the extinction coefficient under what is equivalent to heavy traffic conditions (calculated average CO concentration, $\sim$ 15 parts per million) corresponds to reducing by half the visual range of lights or of prominent dark objects commonly used as daytime visibility markers. These results point up the complexity of the issue of the removal of lead from gasolines and the need for careful consideration of the consequences of such action.

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References and Notes

1. A measure of atmospheric clarity is the meteorological range, L_V, computed from the extinction coefficient, b_{ext}, by means of the formula $L_V = 3.9/b_{ext}$ for an assumed 2 percent contrast threshold [W. E. K. Middleton, *Vision through the Atmosphere* (Univ. of Toronto Press, Toronto, 1952), pp. 103–105]. In urban atmospheres, the contributions of molecular scattering and absorption to extinction can, in general, be ignored [R. J. Charlson, *Environ. Sci. Technol.* **3**, 913 (1969)]. It is also customarily assumed, in lieu of adequate measurements, that the extinction component due to absorption by aerosol particles is negligible, whence the expression for meteorological range depends only on the scattering coefficient of the aerosol particles, b_{scat}, namely, $L_V = 3.9/b_{scat}$. There is indirect experimental justification for this assumption [H. Horvath and K. Noll, *Atmos. Environ.* **3**, 543 (1969)].
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9. Report No. 17913 of the Working Party, "Methods of Measuring Air Pollution" (Organisation for Economic Co-operation and Development, Paris, 1965).
10. It is assumed that molecular scattering and absorption are negligible, so that the extinction coefficient is the sum of the aerosol scattering and absorption coefficients. The increase in the extinction coefficient is the difference between the final extinction coefficient, computed by Beer's law from the transmittance measured after 24 cycles of driving, and the initial extinction coefficient, assumed to be equal to the initial scattering coefficient; the increase in the scattering coefficient is the difference between the final average scattering coefficient (over the same path viewed by the transmissometer) computed from the nephelometer traverse record and the initial scattering coefficient; the increase in the absorption coefficient is the difference between the increases in the extinction and scattering coefficients. Only the lower limit of the increase in the scattering coefficient was determinable from one of the four tests with each fleet. But, since the increase in the scattering coefficient can be no greater than the increase in the extinction coefficient, the ranges of mean increase of scattering and absorption coefficient were calculable.
11. I thank the Pennsylvania Turnpike Commission for the use of the Sideling Hill tunnel, and my colleagues at Du Pont for their assistance in this work.

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Population Modeling: A Systems Approach

Abstract. *A single species population dynamics model based on the functional representations of birth, growth, and death has been constructed. Laboratory parameter estimates were used in a computer implementation of the model to simulate field populations. Preliminary results of replicate runs with parametric sampling indicated reasonable statistical agreement. Further development with the systems analysis technique is planned.*

Mathematical modeling has brought about revolutionary advances in the physical sciences. One aspect of modeling is the elucidation of the essence of a system, to provide better understanding of the complexities of its natural behavior. Faced with the vast variability present in ecosystems, engineers, biologists, and other scientists can benefit from application of mathematical modeling techniques. Several guidelines for modeling systems should be considered.

1) Initially, the scientist must define the problem, distinguishing it from the rest of the surrounding universe. We choose the problem as the study of the population dynamics of a single species and the universe as everything else. The level of organization selected reflects the degree of resolution desired.

2) The next step is the selection of system components. The component must be a coherent entity at a lesser level of organization than the problem at large. For convenience a good first guess is that the components should be the largest coherent subsets which, when combined, capture the essence of the problem.

The best set of components, although not unique, will be that set which reflects the primary functional characteristics of the modeling problem. A production-ecologist might lump species populations into functional arrays (producers, consumers, and the like) as his components. The functions to be modeled dictate the selection of components.

In this single species model of population dynamics the primary functional considerations are birth, growth, death, and temperature effects. While individual instars (life stages) readily suggested themselves as system components, functional considerations challenged this approach. The homogeneity of rate functions of the first six instars of the freshwater shrimp *Hyalella azteca* led to the grouping of these six into one component. Each of the remaining six instars were sufficiently variable to consider each of them as a separate component. These breakdowns were strictly on the basis of functional discreteness.

3) Each individual component must be given a free body characterization. The component is given a mathematical description which interrelates the inputs, outputs, and states of the system. The component is considered as a discrete package in its entirety. It is in this procedure that the biological intuition and understanding is incorporated into strict mathematical formalisms. Any gross assumptions or simplifications concerning either the biology or the mathematics must be made explicit.

The state variables must be chosen so that they encapsulate the functions of the component. In a population dynamics model, in which grouped instar components are used to generate numerical changes in population size, the state variable can be population size. There must be a relation between the terminal (input-output) variables and the state variables. These relations must be the essence of the component in isolation.

4) The linkage of components is essentially simple. The outputs of one become the inputs to other components. This does not necessarily infer a tem-