SECTION F, GEOGRAPHY

Factors of Temperature and Humidity in Relation to Aircraft Performance

THOMAS L. BRYANT, Norman

Not too long ago it was found necessary to write to many government agencies and international airlines in order to obtain material for a research paper dealing with the aviation climatology of the Eastern Mediterranean. The paper was to represent a venture in the application of geographical techniques in regard to air transport operations. Among the many responses received was a rather surprising letter from the Staff Vice President (Flight Operations) of an important United States flag carrier engaged in international air transport operations. The letter advised that "With the advent of modern aircraft and ground based electronic navigation aids, the need for detailed geographical data became obsolete".

About a week after this letter was received, newspapers announced the tragic news of a major airline disaster. A multi-engine jet transport, designed to operate at altitudes of thirty and forty thousand feet, had crashed against the side of a hill which measured less than three thousand feet in height above the level of the Caribbean Sea.

This unhappy incident readily suggests that geography is not obsolete in regard to aviation despite the remarkable progress made in aircraft design and navigation equipment since World War II. Future aeronautical developments point to ever increasing speeds and operational altitudes but geography will still be an important consideration. The supersonic transports of the future must still maneuver to land at airports in which factors of local terrain and climate will continue to create problems just as they do today and have done in the past.

As aeronautical technology has developed to permit increased speeds and operational altitudes, a function (in part) of low-drag design, greater concern has developed among airmen regarding aircraft performance. This is considered a critical area requiring detailed analysis for each flight. Questions pertaining to runway requirements for takeoff and landing and single-engine performance must be answered in terms of both safety and economics. Consideration must be given to such factors as aircraft gross weight, power available, the effect of wind and especially temperature/humidity conditions in order to answer such questions.

This paper concerns some suggested climatological techniques regarding temperature and humidity which would be useful for long-range planning purposes in the sector of economic analysis of air transport operations. Presented in a generalized graphic form, climatological data pertaining to aircraft performance may also be useful in pilot route indoctrination programs. It must be stressed that this paper does *not* recommend the use of climatological averages in the operation of specific flight missions. At this point, safety considerations demand the employment of meteorological data obtained at the time of flight and while the flight is in progress.

Invisible to the pilot but effecting the performance of his aircraft as surely as other conditions which are more easily discernible, are the factors of temperature and humidity. The pilot is thoroughly familiar with the performance of his aircraft under average atmospheric conditions as presented in flight operations instruction manuals. He is also aware of the

vital necessity to correct his operating techniques, using performance data charts, when existing conditions vary from the "average".

Aircraft performance is usually established in relation to standard day criteria represented by sea level dry-air conditions of 29.92 inches of mercury atmospheric pressure at a temperature of 59 degrees Fahrenheit. Up to the base of the stratosphere, temperature variation with height is considered linear so that a lapse rate of 3.57 degrees Fahrenheit per thousand feet exists within the standard atmosphere. (United States, Department of the Air Force, 1954).

Temperatures higher than standard affect aircraft performance adversely by raising the density altitude or the local density environment existing around the airplane. Water vapor in the atmosphere, generally of negligible effect in cruising flight, has an observable deleterious effect on engine power under conditions of high power and low altitude. Atmospheric moisture, by replacing some molecules of air within the local environment contributes to a reduction of air density which also reduces pressures within the combustion chambers of the aircraft engine. Engine power is consequently reduced by the presence of atmospheric moisture.

Increases in density altitude (pressure altitude corrected for nonstandard temperature conditions) thus represent an increase in effective operating altitude. Increases in operating altitude result in lengthened takeoff and landing ground roll, higher true stalling speeds, a reduction in rate of climb and other factors. As an example, the sea level takeoff ground roll of the Douglas DC-3 aircraft is increased approximately ten per cent at temperatures of 75 degrees Fahrenheit and twenty per cent at 100 degrees Fahrenheit. Aircraft propellers, actually rotating airfoils, similarly become less efficient under conditions of reduced air density. Aircraft engine power loss can also be approximated for purposes of illustration. Performance engineers expect a 1.5 per cent power loss for each 9 degrees (Fahrenheit) temperature increase above standard day conditions. Eight per cent of total engine power is lost when the specific humidity reaches 0.03 pounds per pound of dry air (United States, Department of the Air Force, 1954).

The loss of aircraft and engine performance, occasionally forcing a reduction in cargo or passenger carrying capability for the sake of safety, represents lost revenue for air transport operators. These factors should be carefully considered in the economic analysis of proposed equipment to be used on air routes in those parts of the world in which high temperatures and humidities may be expected as a matter of course.

An example of such a "temperature/humidity region" is furnished by the summer climate of the Eastern Mediterranean. Summer conditions in this area include some of the hottest temperatures recorded on earth; this heat, in the lower levels, is commonly associated with very high humidity. These high temperatures and humidities complicate aircraft operations in an area where mountainous terrain frequently requires the pilot to climb his airplane directly to a moderately high cruising altitude.

The average date that a temperature threshold of 70 degrees Fahrenheit is crossed through seasonal conditions furnishes a clue to a critical season from the standpoint of takeoff and one-engine-inoperative-climb calculations for airports with runways of marginal length. In the Eastern Mediterranean this threshold is crossed between the fifth of May and the tenth of June as the hot season approaches; it is again crossed in the month extending from the twenty-fifth of September to the twenty-fifth of October (Conrad, 1943).

The possibilities of a regional analysis of the Eastern Mediterranean in terms of aircraft performance are practically limitless. Two examples may furnish direction to some of the techniques involved in the analysis

of aircraft performance on a climatological basis. The first example approximates expected power loss for reciprocating aircraft engines in general. The second example is furnished to indicate the graphic presentation of the expected performance of a specific aircraft type.

Information pertaining to anticipated power loss and specific humidity during the month of June at selected hours and air terminals within the area of the Eastern Mediterranean is presented in Table I. To clarify the method of construction of this table, the example of the Maritsa Airport, Rhodes, Greece, will be used. The existence of standard day pressures and a standard temperature lapse rate is assumed in the calculations presented. In the case of this airport the mean value of all observations was used instead of average relative humidity obtained from a standard hour of observation.

According to data available, the average relative humidity during the month of June at Maritsa is 70 per cent; average daily maximum temperature is 78 degrees Fahrenheit (Great Britain, Air Ministry, 1958). Assuming standard conditions, the pressure altitude at this station will be similar to its actual elevation—approximately 300 feet. Entering a psychrometric chart with this data, a specific humidity of 0.015 pounds per pound of dry air is obtained. Using another very simple chart, an indication of the power loss — 4.8 per cent of total dry power, is revealed. The tabular information derived is obviously amenable to a map presentation.

Thus far this paper has been concerned almost exclusively with the factors of temperature and humidity in relation to "normal" aircraft operations. Another series of important studies could concern the analysis of temperature and humidity factors in relation to emergency situations such as mechanical malfunctions requiring engine shutdown during flight. Performance restrictions caused by the loss of such large scale units of power become dramatic when flight is conducted over high terrain. Calculations might reveal that a safe terrain clearance altitude could not be maintained with the power remaining. This factor must be carefully considered for low and medium performance twin-engine aircraft where the loss of one engine represents a loss of 50 per cent of total power available.

Figure 1 depicts terrain in the area of the Eastern Mediterranean which is above the single engine capability of a lower performance transport airplane, the Douglas DC-3, which is in widespread use in this part of the world. The performance of the aircraft was studied at the nominal gross weight of 26,000 pounds which is slightly higher than the allowable operational weight of DC-3's in regular airline service but well below the maximum weight authorized in military flying. The term "single-engine-service-ceiling" is defined as the maximum altitude at which a rate of climb of 100 feet per minute could be maintained with one engine operating at the maximum continuous power at which damage would not be sustained. Assuming the existence of a standard temperature lapse rate, the map comprising Figure 1 is based on the average highest temperatures of the summer months of June, July, and August as measured at fourteen selected stations in the Eastern Mediterranean area. Standard U.S. Air Force single-engine performance charts were used and revealed that the single-engine service ceiling ranged approximately from 3,800 feet in the northern sector to 2,800 feet in the southern portion of the Eastern Mediterranean. The shaded area on the map thus generally represents dangerous territory for the pilot of a loaded DC-3 operating on one engine.

These examples serve to point toward a possible "regional climatology of aircraft performance". It is hoped that this paper and these examples suggest the necessity for the application of geographical methods in the general field of aviation.
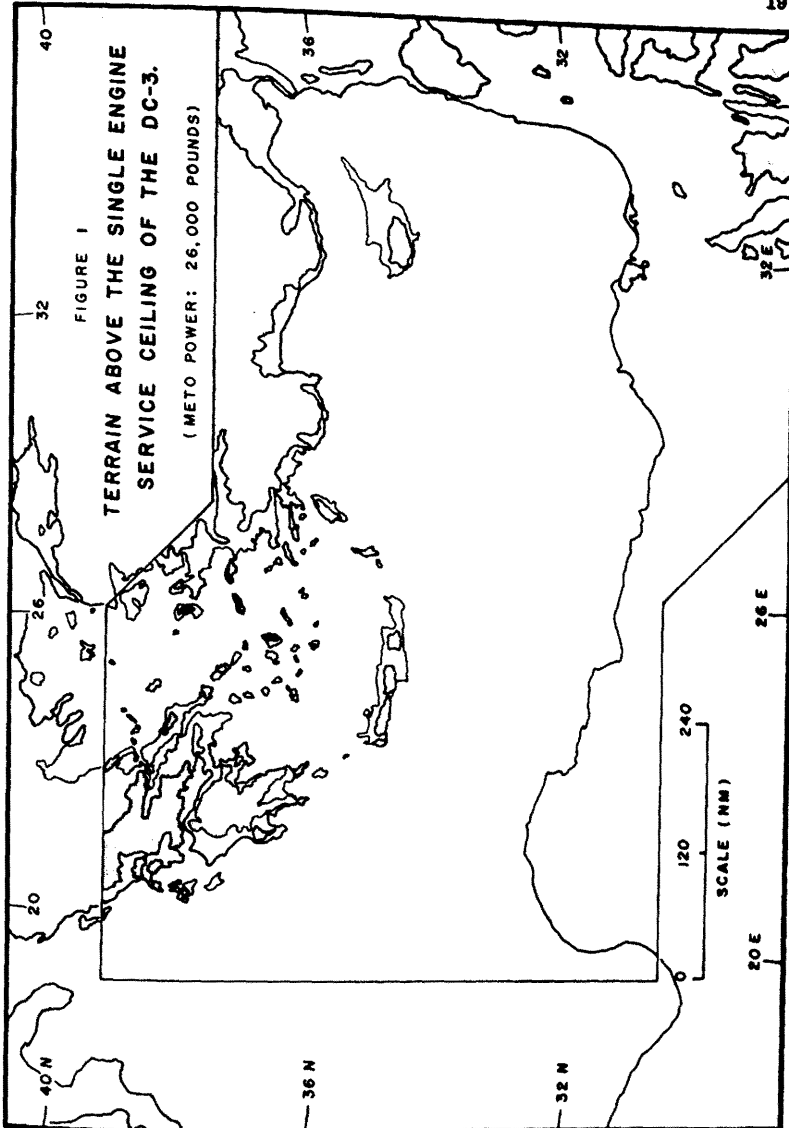
TABLE I. POWER LOSS AND SPECIFIC HUMIDITY DURING THE MONTH OF JUNE AT SELECTED HOURS AND AIR TERMINALS: EASTERN MEDITERRANEAN

(Standard day pressure and temperature lapse rate is assumed.)

Air Terminal*	Time* of Obs. (LST)	Pressure* Altitude (ft.-MSL)	Relative* Humidity (%)	Specific** Humidity (#/# dry air)	Power** Loss (% of total dry power)
Benghazi, Libya	0930	Sea Level	53	.009	2.8
El Adem, Libya	0430	500	85	.027	9.0
Alexandria, Egypt	0800	Sea Level	72	.016	5.2
Cairo, Egypt	0800	400	55	.010	3.2
Haifa, Israel	0830	Sea Level	67	.014	4.5
Amman, Jordan	0830	2,500	40	.005	1.6
Jerusalem, Jordan	0830	2,500	48	.008	2.6
Damascus, Syria	0830	2,400	45	.007	2.2
Beirut, Lebanon	0900	Sea Level	67	.014	4.5
Adana, Turkey	0730	Sea Level	74	.019	6.0
Izmir, Turkey	0700	Sea Level	56	.010	3.2
Athens, Greece	0730	Sea Level	61	.012	3.8
Iraklion, Crete	0730	100	58	.009	2.8
Rhodes, Greece	0730	300	70	.015	4.8
Mean					

*Great Britain, Air Ministry, *Tables of Temperature, Relative Humidity, and Precipitation for the World* (London: Her Majesty's Stationery Office, 1958).

**Computed from: United States, Department of the Air Force, *Aircraft Performance Engineering* (Washington: Government Printing Office, 1954).

FIGURE 1

TERRAIN ABOVE THE SINGLE ENGINE
SERVICE CEILING OF THE DC-3.
(METO POWER: 26,000 POUNDS)

LITERATURE CITED

Conrad, V. 1943. The climate of the Mediterranean Region. Bull. Amer. Met. Soc. 24: 127-145.

Great Britain, Air Ministry. 1958. Tables of temperature, relative humidity, and precipitation for the world: Part III, Europe and the Atlantic Ocean north of 35° north. London.

United States, Department of the Air Force. 1954. Aircraft performance engineering. Washington, D.C.