TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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No. 287

EFFECT OF ALTITUDE ON POWER OF AVIATION ENGINES.

By Italo Raffaelli.

From "Rendiconti Tecnici," July 15, 1924.

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NOTICE

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EFFECT OF ALTITUDE ON POWER OF AVIATION ENGINES.*

By Italo Raffaelli.

These notes are intended to furnish practical and general data on the effect of altitude on engine power. The effective horsepower of an engine is a function of the mean pressure of the fluid acting on the pistons, of the R.P.M. of the engine and of the mechanical efficiency. The mean pressure is directly proportional to the calories given out by the fuel, i.e., to the weight of the mixture (of air and gasoline in the right proportion) introduced into the cylinders and to the thermal efficiency of the engine cycle.

Inasmuch as the carbureters of aviation engines are provided with devices for keeping the ratio of the gasoline and air nearly constant and assuming the thermal efficiency ($\eta_t = 1 - \frac{1}{p^{0.3}}$, in which p = the compression ratio) to be constant for a given engine, so that the compression ratio remains constant, it follows that the mean pressure in the cylinders varies directly as the weight of the air taken in by the engine. Therefore in normal engines (not provided with superchargers) this weight and, consequently, the said mean pressure are directly proportional to the density of the air, which varies with the altitude as indicated by the curve in Fig. 1.

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* From "Rendiconti Tecnici," July 15, 1924, pp. 14-20.

The R.P.M. of an engine (with throttle wide open at all altitudes) decreases slightly with increase in altitude. In passing from 1000 to 4000 m (3280 to 13120 ft.) the R.P.M. decreased about 1/11, following the line shown in Fig. 2.

This decrease in propeller speed is responsible for the decreased speed of the airplane at high altitudes, which speed decreases more rapidly than the propeller speed.

The mechanical efficiency decreases as the altitude increases, because the resistance of most of the parts of an engine, such as the valve gear, magnetos and pumps, remains nearly constant, while the indicated horsepower decreases. A good average of the variation of the mechanical efficiency is shown by the curve in Fig. 3.

Due to the above-mentioned factors, the brake power of an aviation engine decreases more rapidly with increase of altitude than the air density decreases. For ordinary engines, this decrease in power follows approximately the curve of barometric pressure.

Hence the practical rule that "with increase of altitude, the decrease in engine power is nearly proportional to the corresponding decrease in atmospheric pressure."

Figs. 4-6 give the pressure curves at various altitudes and the equivalent curve (Fig. 6) of the ratios of power (taking 1.00 as the power at 0 altitude). In Fig. 6, curves 1 and 2 are respectively the altitude-power curves of the American engines E (200 HP) and H-3 (325 HP). Curve a represents the variations in power of these two engines furnished by the Wright Company. This curve nearly coincides with that of the barometric pressure and confirms the law already stated.

Effect of altitude on consumption of fuel and oil.- If the carbureters are so adjusted as to keep the ratio of weight of fuel to weight of air constant, the fuel consumption per one horsepower-hour remains constant and the hourly consumption varies in proportion to the power.

Practical experiments, however, indicate the advisability of slightly enriching the mixture as the altitude increases (i.e., as the final compression decreases), so that the methods of carbureter adjustment are based on this principle. The specific fuel consumption varies practically as indicated by Fig. 7. The hourly consumption varies as the product of the power by the specific consumption at the various altitudes, i.e., according to Fig. 8 (taking 1 as the specific consumption at altitude 0). The maximum flight duration in hours at the various altitudes is inversely proportional to the hourly consumption and therefore varies as the curve in Fig. 9, which gives the maximum flight duration in hours at altitude 0.

The hourly consumption of oil, on the other hand, remains practically constant at all altitudes. The oil tanks should hold enough oil for the maximum flight duration at the highest altitude for sustained flight, as determined for each airplane.

The following tables give the variations in the density of the air, mechanical efficiency, atmospheric pressure, engine power, consumption of fuel and oil, and maximum flight duration at various altitudes from 0 to 7000 meters (nearly 23,000 feet).

Altitude in meters	Air density ratio	Mechanical efficiency	Atmospheric pressure in mm.
0	1,000	0,860	760
500	0.948	0.852	716
1000	0.899	0.845	675
1500	0.862	0.838	634
2000	0.808	0.830	596
2500	0.765	0.820	560
3000	0.729	0.811	526
3500	0.693	0.799	494
4000	0.657	0.788	463
4500	0.622	0.776	433
5000	0.591	0.764	406
5500	0.559	0.750	379
6000	0.530	0.735	354
6500	0.501	0.717	330
7000	0.479	0.700	309

B.H.P.	$\frac{c}{c_o}$ Specific fuel consumption	$\frac{W}{W_o}$ Fuel consumption per hour	$\frac{Hr}{Hr_o}$ Hours of flight
1.000	1.000	1.000	1.000
0.941	1.015	0.955	1.005
0.887	1.031	0.914	1.094
0.833	1.047	0.874	1.144
0.783	1.063	0.836	1.196
0.736	1.081	0.784	1.275
0.691	1.101	0.762	1.312
0.649	1.120	0.728	1.374
0.608	1.141	0.694	1.441
0.569	1.161	0.663	1.508
0.534	1.183	0.633	1.580
0.498	1.210	0.604	1.656
0.453	1.231	0.576	1.736
0.434	1.255	0.550	1.818
0.406	1.281	0.525	1.905

Translated by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

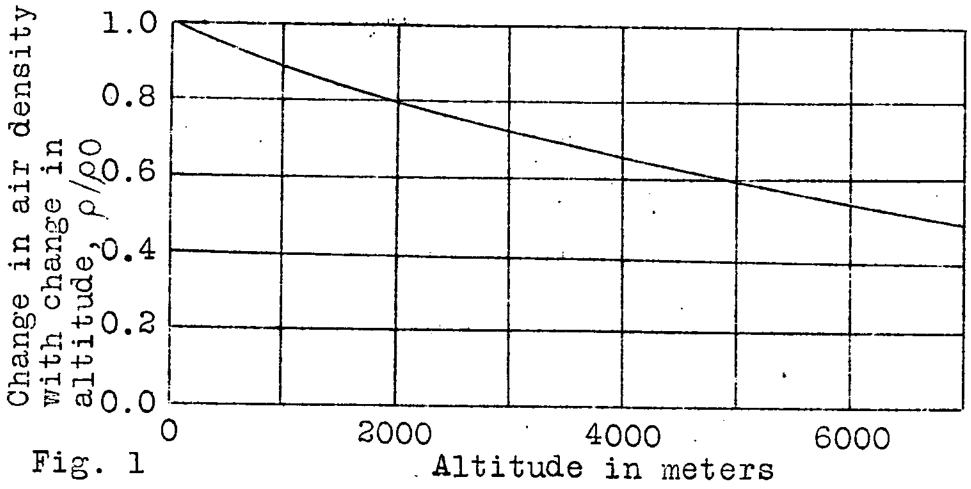
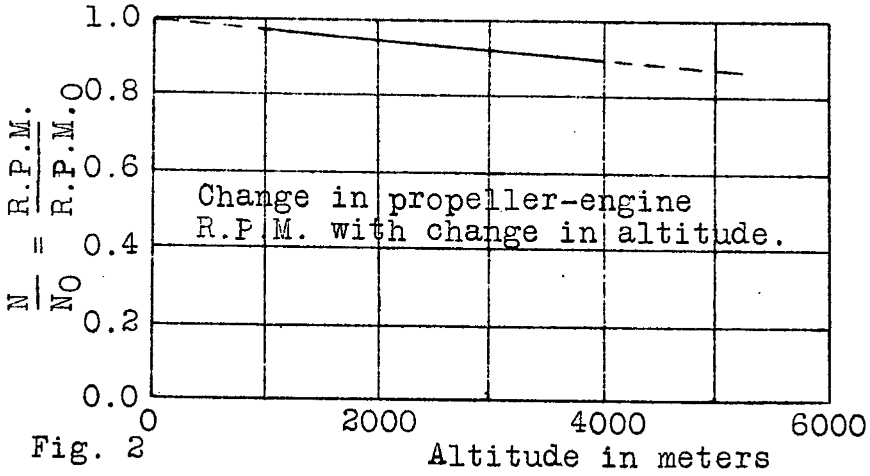


Fig. 1



Change in propeller-engine R.P.M. with change in altitude.

Fig. 2

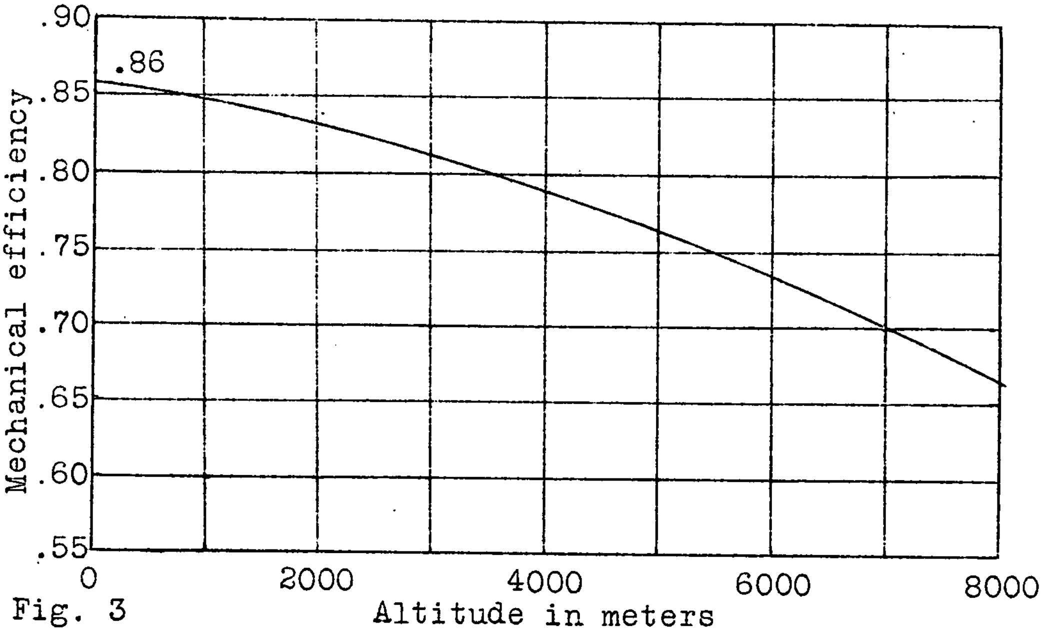


Fig. 3

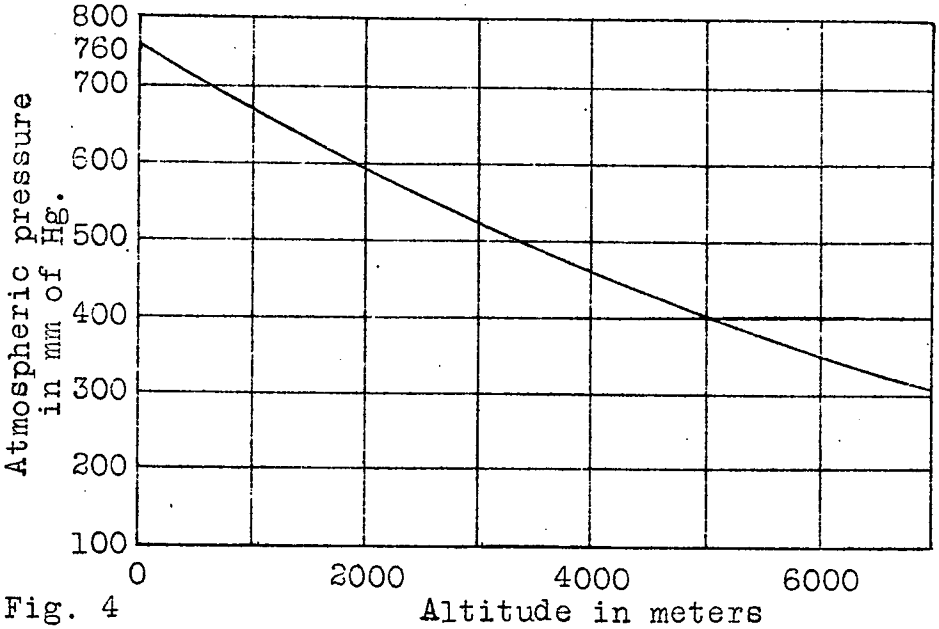

Atmospheric pressure in mm of Hg.
800
760
700
600
500
400
300
200
100
0
2000
4000
6000
Altitude in meters

Fig. 4

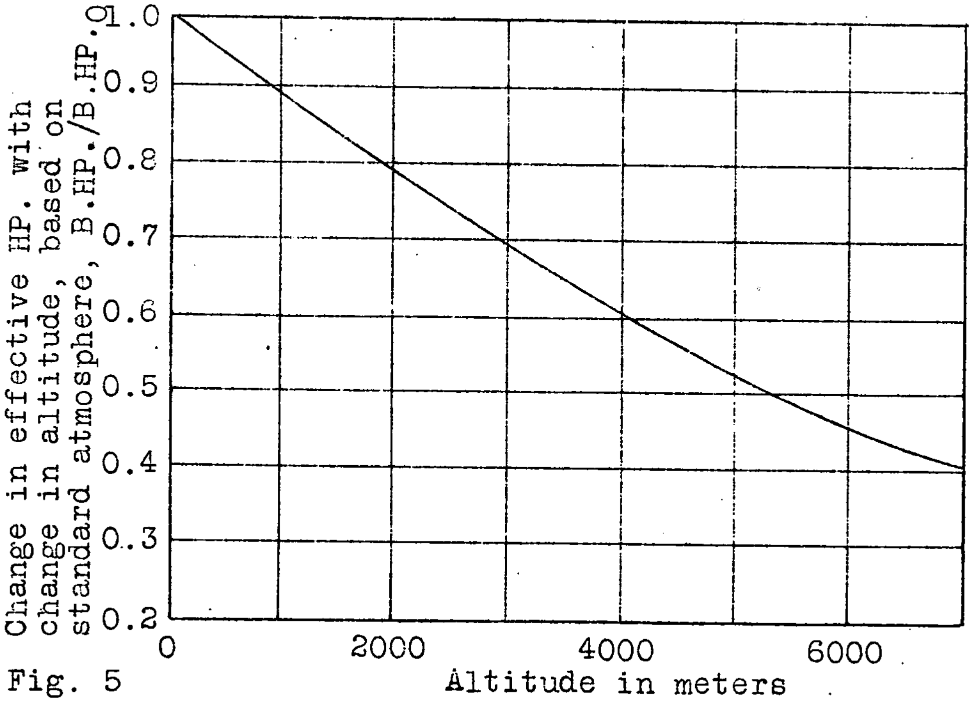

Change in effective HP. with change in altitude, based on standard atmosphere, B.HP./B.HP.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2000
4000
6000
Altitude in meters

Fig. 5

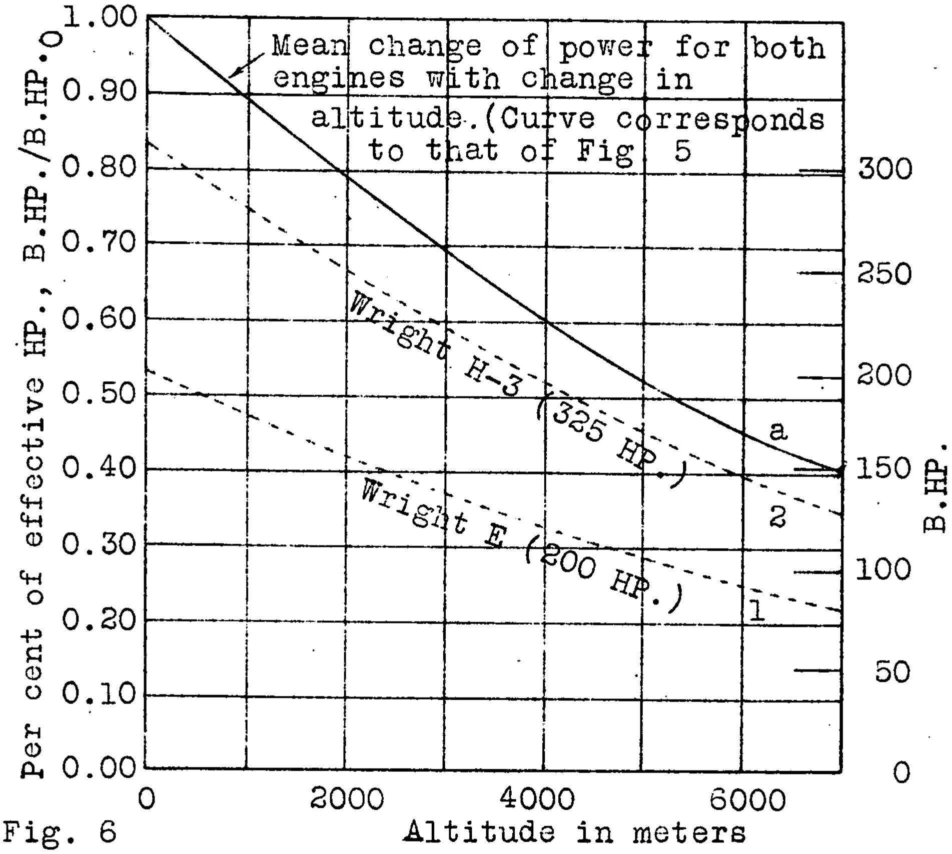

Mean change of power for both engines with change in altitude. (Curve corresponds to that of Fig 5
Wright H-3 (325 HP.)
Wright E (200 HP.)
a
2
1
Per cent of effective HP., B.HP./B.HP.$_0$
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
B.HP.
300
250
200
150
100
50
0
0
2000
4000
6000
Altitude in meters

Fig. 6

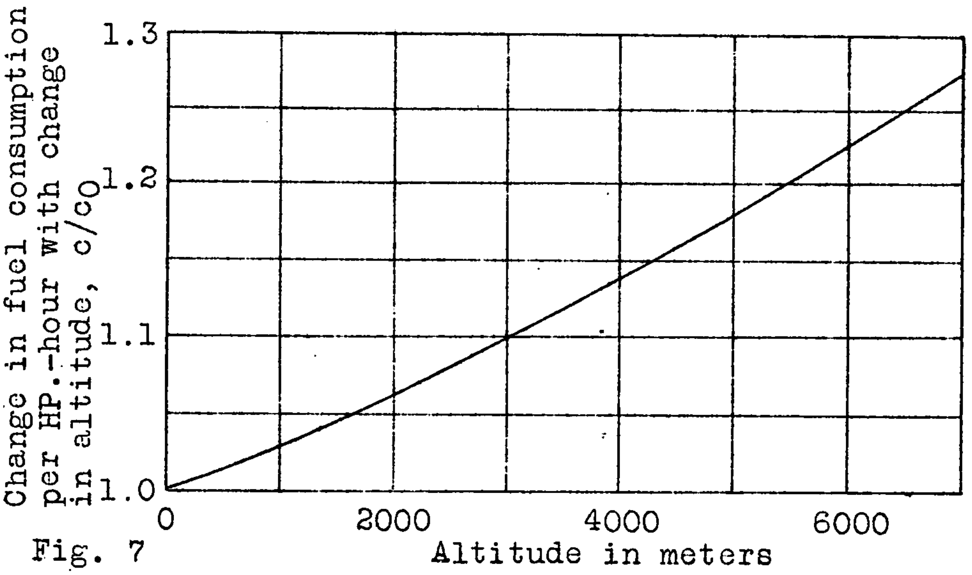

Change in fuel consumption per HP.-hour with change in altitude, c/c$_0$
1.3
1.2
1.1
1.0
0
2000
4000
6000
Altitude in meters

Fig. 7

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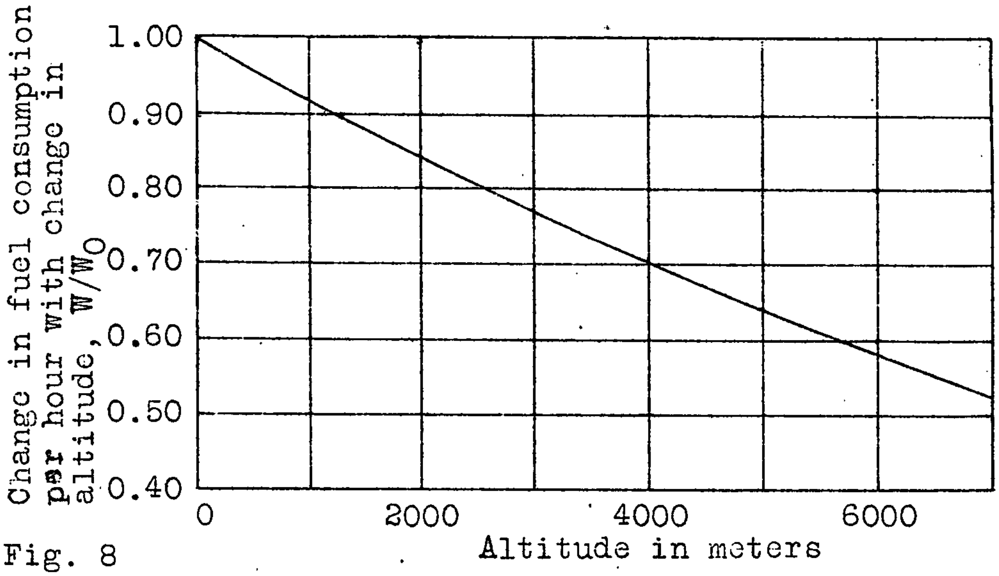
Change in fuel consumption per hour with change in altitude, W/W_0
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0
2000
4000
6000
Altitude in meters

Fig. 8

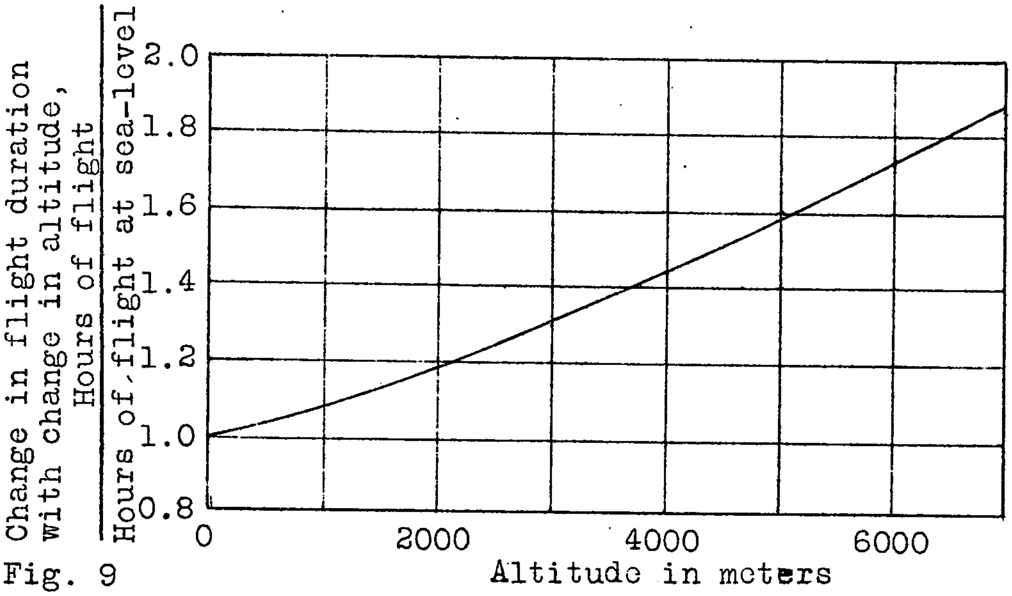
Change in flight duration with change in altitude, $\frac{\text{Hours of flight}}{\text{Hours of flight at sea-level}}$
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
2000
4000
6000
Altitude in meters

Fig. 9

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