Engines for UL-aircraft - influence of ambient air temperature and barometric pressure on engine performance and carb calibration

1) Introduction and general declarations:

In an internal combustion engine the calorific value of the fuel is transformed into heat and part of it (depending on efficiency) into mechanical energy. For the combustion process the oxygen (O_2) of the ambient air is needed.

For the perfect combustion of 1 kg gasoline 14,6 kg air is necessary. (stochiometric $\lambda = \frac{L}{L\ \text{theor.}} = 1$)

This ratio will deviate in practical engine design more or less from its ideal value. With a surplus of fuel ($\lambda<1$) the mixture is considered as "rich" and with lack of fuel ($\lambda>1$) the mixture is declared as "lean".

Mean density of air at sea level: $\rho_o = 1{,}29\ kg/m^3$

2) Influence of air density on performance and operation:

Any changes of barometric pressure and air temperature corresponding to altitude and climatic condition will vary air density and therefore affect the air/fuel mixture as well as the quantity of air aspirated by the engine.

Consequently performance and operational behaviour will be influenced to a great extent.

Even on engines running at the same altitude, differences in performances of 10% and more will be noticed between operation in cool, high barometric pressure condition and humid high temperature weather.

Such aggravating changes of climatic conditions might happen within one day. In general, air density decreases with increasing altitude.

The influence of the humidity is of minor influence and not considered.

3) Determination of actual engine performance:

The actual performance is calculated from the nominal performance P_o as specified by the manufacturer by multiplication with the density ratio ρ/ρ_o as per enclosed table.

$P = P_o \cdot \rho/\rho_o$

3.1) See example ①:

According to data sheet the nominal performance is 28 kW (38 HP) at ambient air condition of 1013 mbar barometric pressure and 15°C.

To determine the actual performance at 925 mbar barometric pressure and ambient temperature of 30°C enter the table accordingly.

The table shows a density ratio ρ/ρ_o of 0,86.

The actual useable performance:

P = 28 kW (37,5 hp) x 0,86 = 24 kW (32,2 hp)

This is a drop to 86% of its specified value and it should be taken into consideration when approaching airports at high altitide or flying across mountains.

If an altimeter is available procede as follows:

Set the altimeter to standard reference of 1013 mbar (hPa). In example ① it will show 800 m according to 825 mbar pressure. The reading for the density ratio is 0,86 as above.

3.2) Example ②:

Same location as in example 1, but high barometric pressure, and low temperature.
t = -15°C, barometric reading 1000 mbar

Density ratio according to table ρ/ρ_o = 1,1. The reading on the altimeter with standard setting will show 100 m.

P = 28 kW (37,5 hp) x 1,1 = 30,8 kW (41,3 hp)

The increase in performance is 10%.

3.3) Example ③:

An essential loss of performance must be considered on airports at high altitudes like 2640 m above sealevel in Bogota or 4100 m above sealevel in La Paz.

Performance level in La Paz will drop to around 60% of its nominal value.

Special care must be taken in these areas that the used power plant is well sized to ensure sufficient climbing performance.

All the above stated performance corrections assume optimum carburetor calibration. The performance loss will be even quite bigger when using non corrected carbs.

4) Correction of carb calibration:

The calculated performance corrections are valid only if air/fuel mixture is correct. As the mixture ratio changes with the condition of air, correction of the carb calibration will be necessary because of the initial setting by the engine-manufacturer for operation at sealevel $\rho/\rho_o = 1$).

A carb calibration too rich, revealed by a plug face dark brown to black, will result in loss of performance, spark plug fouling and deposits which could lead to engine malfunctions.

Calibration too lean (plug face light brown to white) will lead to high combustion - plug seat - and exhaust temperatures and could cause engine damage and must therefore be avoided.

In practical operation an exchange of the main jet according to a correction factor is carried out. This correction factor f_D can be calculated from the density ratio or taken direct from the table.

$$f_D = \sqrt[4]{\rho/\rho_o}$$

NOTE: equation $f_D = \sqrt[4]{\rho/\rho_o}$ may be solved alternatively by taking twice the square root of the density ratio $f_D = \sqrt{\sqrt{\rho/\rho}}$

Determine the new main jet by multiplying the existing main jet number by the correction factor $mj_{new} = mj_{exist.} \times f_D$

NOTE: this particular calculation of f_D is applicable only if numbering of main jets corresponds to jet diameter such as on Bing carbs in ROTAX UL-engines.

4.1) Example ④:

With assumptions and results as in example ① density ratio → $\rho/\rho_o = 0,86$

$f_D = \sqrt[4]{0,86} = \sqrt{\sqrt{0.86}} = 0,963$

With the initial calibration with main jet 160 The new main jet is 160 x 0,963 = 154. Use the nearest available jet size = 155.

4.2) Example ⑤:

With data of operation in wintertime as in example ②:

$\rho/\rho_o = 1,1$ $f_D = \sqrt[4]{1,1} = 1,024$

main jet_{new} = main jet 160 x 1,024 = 163,85. Fit the main jet 165

It shows that the calibration would be on the lean side without correction.

4.3) Example ⑥:

Based on ambient air condition in La Paz (example ③) with density ratio $\rho/\rho_o = 0,6$
$f_D = \sqrt[4]{0,6} = 0,88$
main jet_{new} = mj 160 x 0,88 = 140,8. The correct main jet is 140.

REMARKS: main jets are generally available in steps of 5 (e.g. 155, 160, 165, etc.)

In most cases, this way of carb correction will be sufficient.

REMARKS: For only occassional operations at altitudes up to 4000 m above sealevel the initial serial calibration will be adequate, always provided that power output is sufficient for the particular aircraft.

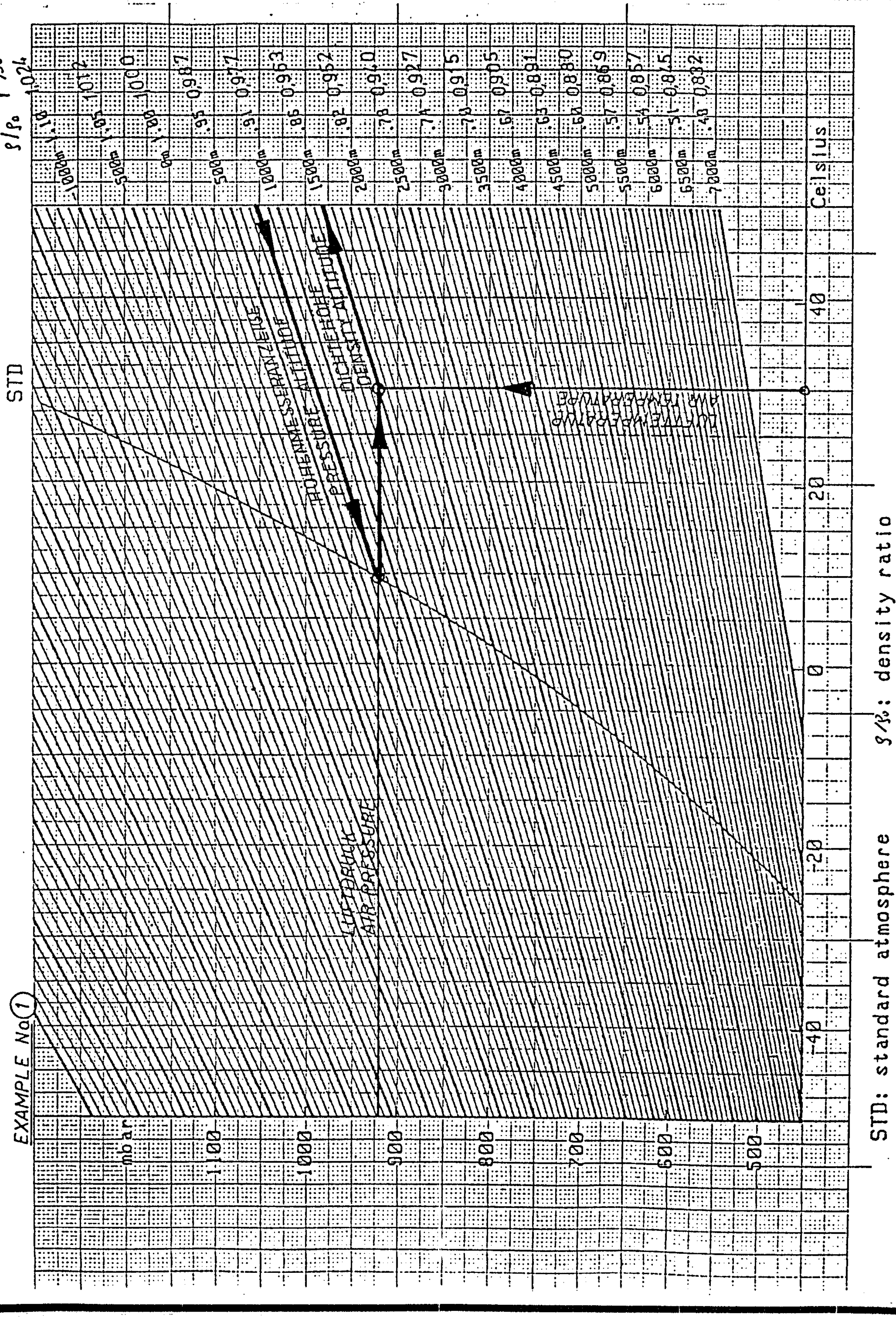
5) Automatic correction of carburetor calibration:

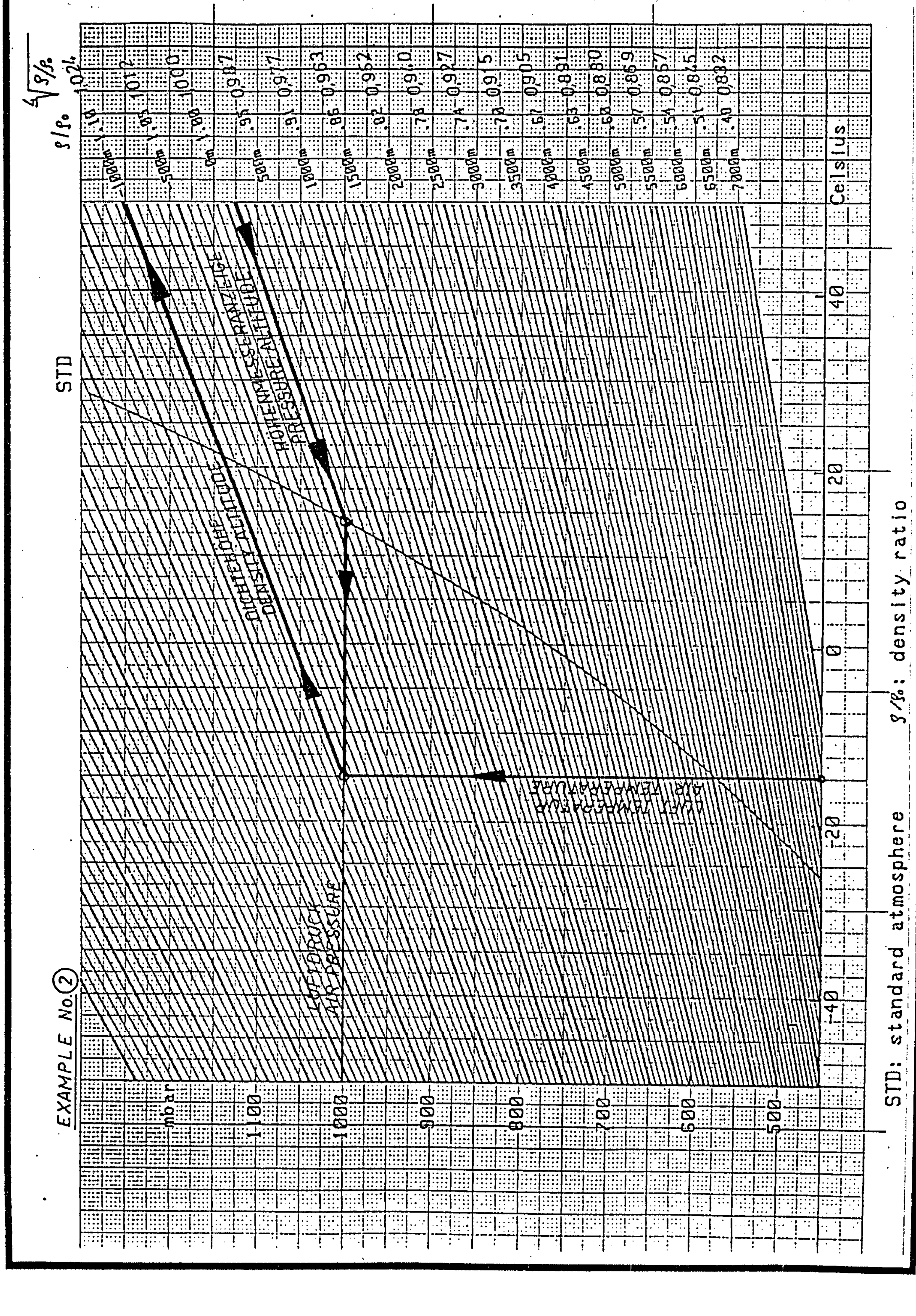
For frequent operations in high altitudes an automatic mixture correction (HAC = high altitude compensator) would be advisable.

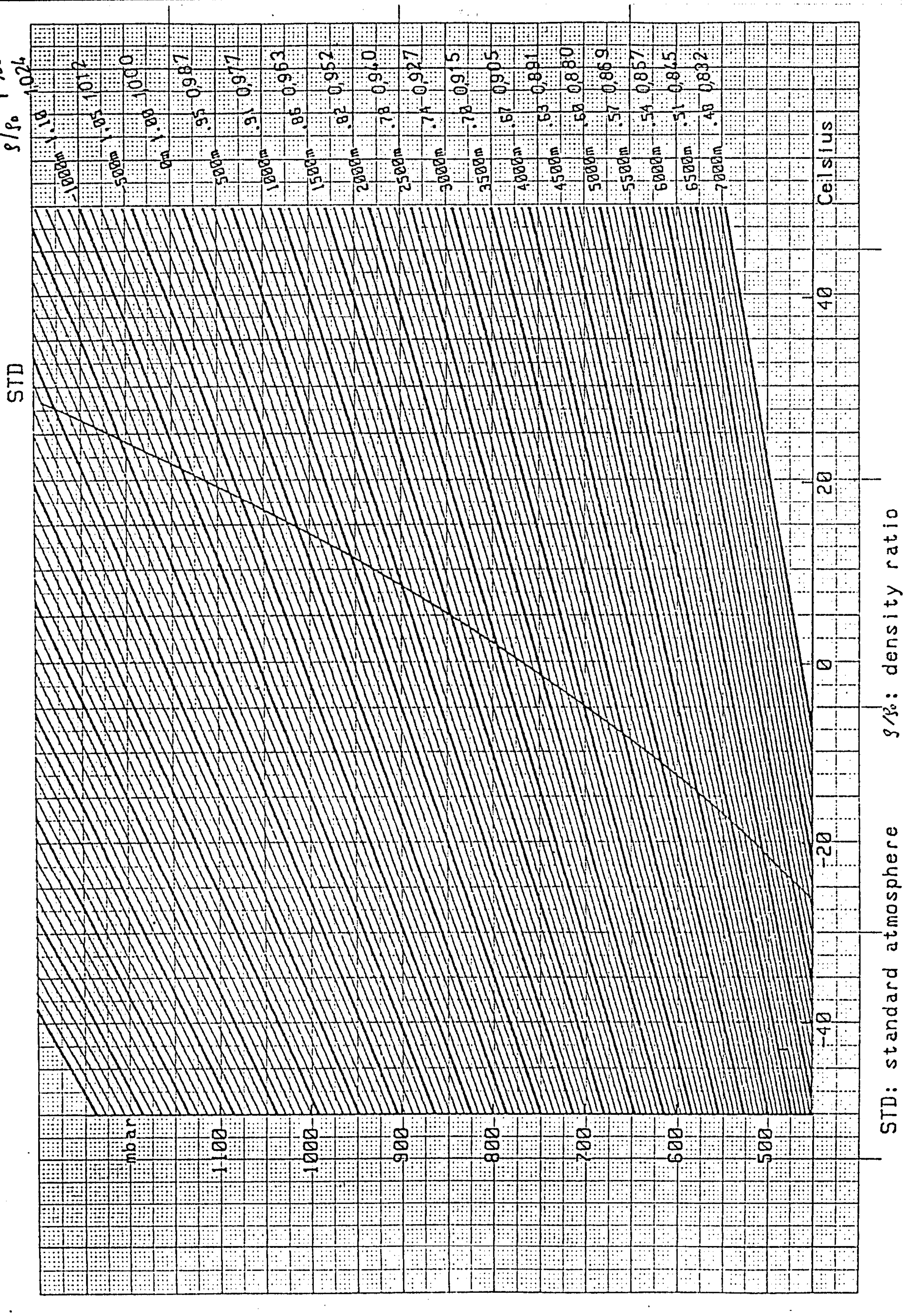
ROTAX offers for some engine types a HAC kit. This kit consists of a HAC and an adapted carburetor.

Please place any inquiries or requests to ROTAX AUSTRIA or any authorized ROTAX dealer.

Enclosure: air-temperature - pressure - density -diagram


EXAMPLE No 1
STD
mbar
1100
1000
900
800
700
600
500
Celsius
40
20
0
-20
-40
HÖHENMESSERANZEIGE
PRESSURE ALTITUDE
DICHTEHÖHE
DENSITY ALTITUDE
LUFTDRUCK
AIR PRESSURE
LUFTTEMPERATUR
AIR TEMPERATURE
-1000m
-500m
0m
500m
1000m
1500m
2000m
2500m
3000m
3500m
4000m
4500m
5000m
5500m
6000m
6500m
7000m
STD: standard atmosphere
ρ/ρ₀: density ratio


EXAMPLE No. 2
STD
mbar
1100
1000
900
800
700
600
500
Celsius
-40
-20
0
20
40
DICHTEHÖHE
DENSITY ALTITUDE
HÖHENMESSERANZEIGE
PRESSURE ALTITUDE
LUFTDRUCK
AIR PRESSURE
LUFTTEMPERATUR
AIR TEMPERATURE
STD: standard atmosphere
ρ/ρ₀: density ratio


ρ/ρ₀
⁴√(ρ/ρ₀)
-1000m 1.10 1.024
-500m 1.05 1.012
0m 1.00 1.000
500m .95 0.987
1000m .91 0.977
1500m .86 0.963
2000m .82 0.952
2500m .78 0.940
3000m .74 0.927
3500m .70 0.915
4000m .67 0.905
4500m .63 0.891
5000m .60 0.880
5500m .57 0.869
6000m .54 0.857
6500m .51 0.845
7000m .48 0.832
Celsius
40
20
0
-20
-40
STD
mbar
1100
1000
900
800
700
600
500
STD: standard atmosphere
ρ/ρ₀: density ratio