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FLIGHT INSTRUMENTS

CHAPTER 4 – THE MACHMETER

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THE MACHMETER

MACH NUMBER

As the true airspeed of an aircraft approaches the speed of sound it is found that are changes in the stability and control of the aircraft. For any aircraft type these changes occur when the true airspeed is a certain proportion of the local speed of sound. The ratio true airspeed to local speed of sound is termed MACH NUMBER.

$$\text{MACH NUMBER} = \frac{\text{TAS}}{\text{Local Speed of Sound}}$$

Mach number is expressed as a decimal, for example M.84. An aircraft cruising at M.84 is maintaining a TAS which is 84% of the speed of sound at the level at which the aircraft is flying.

For high speed aircraft, handling and performance vary with Mach number and so an instrument is required to provide an indication of Mach number. This instrument is the Machmeter.

LOCAL SPEED OF SOUND.

The machmeter correctly shows the ratio of TAS to the local speed of sound, not the speed of sound in the Standard Atmosphere. The speed of sound is a function of temperature, the lower the temperature the lower will be the speed of sound.

A more exact statement is as follows:

$$\text{Local Speed of Sound} \propto \sqrt{\text{Temp}_{\text{KELVIN}}}$$

or

$$\text{Local Speed of Sound (in kts)} = 38.945\sqrt{\text{Temp}_{\text{KELVIN}}}$$

Temperature $_{\text{KELVIN}}$ is measured on the Absolute scale where zero corresponds to -273$^{\text{O}}$C.

FINDING TAS FROM MACH NUMBER AND TEMPERATURE

$$\text{Mach number} = \frac{\text{TAS}}{\text{Local Speed of Sound}}$$

$$\therefore \text{TAS} = \text{MN x LSS}$$

or $$\text{TAS} = \text{MN x } 38.945 \sqrt{\text{Temp}_{\text{KELVIN}}}$$

Example: Find TAS corresponding to M0.8 at FL 310 with a temperature deviation ISA -10

Working: ISA temp at FL310 $= +15 - (31 \times 2)$
$= -47^{\circ}C$

ISA -10 $= -57^{\circ}C$
$= (-57 + 273)_{\text{KELVIN}}$
$= 216_{\text{K}}$

$\text{TAS} = 0.8 \times 38.945 \sqrt{216\text{K}}$
$= 458$ knots.

This calculation can also be made on the navigation computer. This process is studied in more detail in Flight Planning.

PRINCIPLE OF OPERATION

The Machmeter finds Mach number from Pitot (P) and Static (S) pressures using the formula:

$$\textbf{Mach number} = f\sqrt{\frac{P - S}{S}}$$

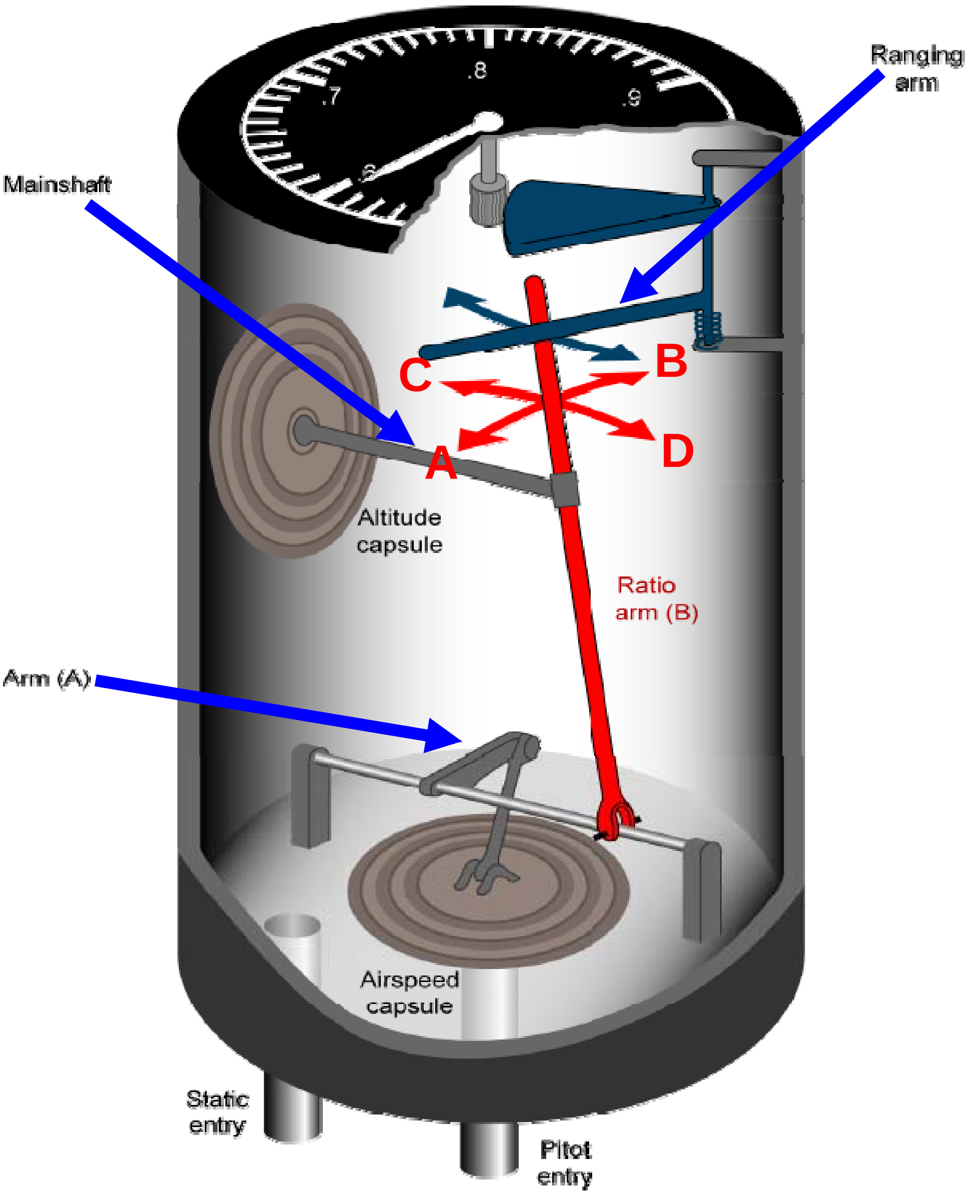
It is not obvious how this relates to the ratio of TAS to the local speed of sound. We know however that TAS is a function of dynamic pressure (P - S) and air density and that the local speed of sound is a function of temperature which in turn is a function of static and air density. As the air density factor is common, the result is an expression of Mach number requiring only Pitot and static inputs.

The instrument, shown in the diagram below, consists of a sealed case containing an airspeed capsule to measure P - S and an altimeter capsule to measure S. The linkage takes care of the function which links Mach number with Pitot and static pressures.

Either increase in airspeed (IAS / CAS / RAS) or increase in altitude will result in increase in Mach number. To allow for this, the ratio arm can move C $\rightarrow$ D (increasing altitude) or B $\rightarrow$ A (increasing airspeed) and either movement will cause the ranging arm to move to register an increased Mach number.

For example, an aircraft climbing at constant IAS is maintaining constant dynamic pressure so no movement is occurring at the airspeed capsule. However as the static pressure reduces, the altitude capsule will expand pushing the ranging arm via the ratio arm to register an increased Mach number.

Various formulae may be used to calibrate the Machmeter, depending on the range of the instrument. The calibration effectively eliminates compressibility error.



ERRORS OF THE MACHMETER

It should be noted that no Standard Atmosphere assumptions are required for the calibration of the machmeter and so no temperature or density errors will occur in non-standard conditions.

The machmeter is subject to the following errors:

INSTRUMENT ERROR

Tolerances in manufacture should not exceed M.01.

POSITION / MANOEUVRE-INDUCED ERROR

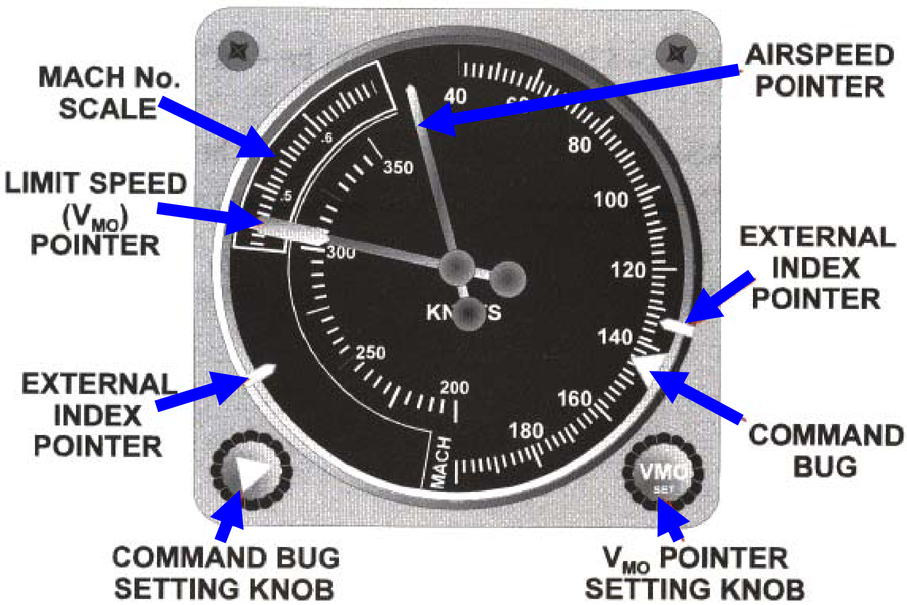
Inaccurate sampling of static pressure affects the accuracy of the instrument.

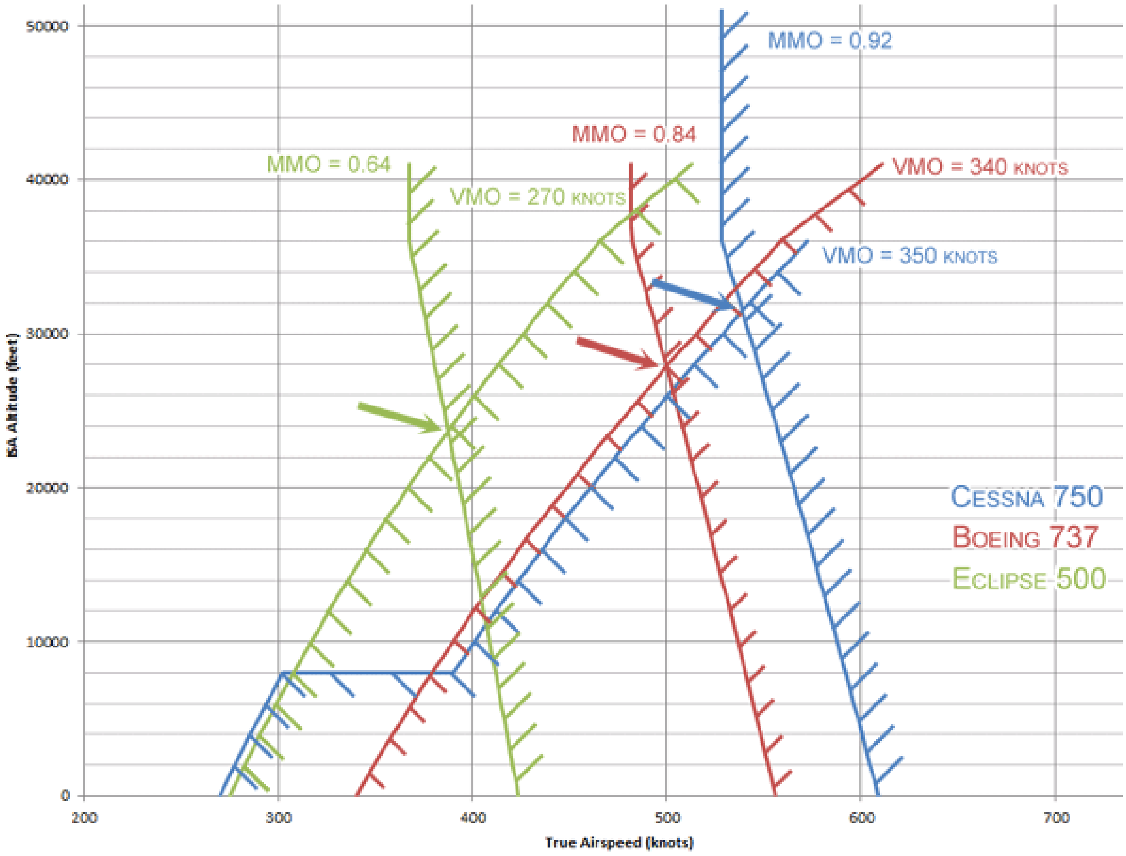
ACCURACY

The overall accuracy associated with the Machmeter is in the range ± M.01 to M.02.

THE MACH / AIRSPEED INDICATOR (MASI)

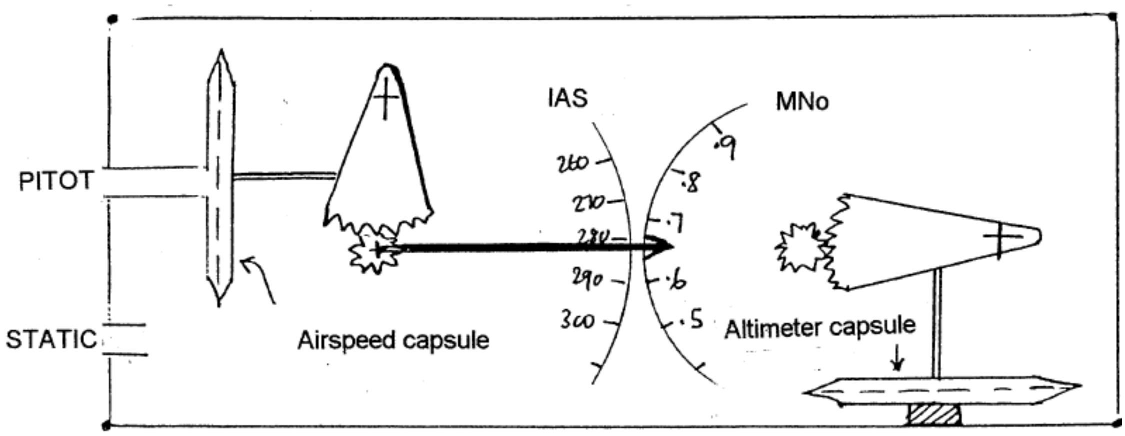
The MASI combines the functions of both a conventional airspeed indicator and a machmeter. The combination saves space in the instrument panel and allows the pilot to monitor both IAS and Mach number in a single display.





It should be noted that at low altitude V_{MO} is more limiting than M_{MO} but this relationship is reversed at high altitude. Limiting speeds may be shown as additional (red) needles.

A schematic diagram of a basic Mach / Airspeed Indicator is shown below.



In addition to providing displays of airspeed and Mach number, the MASI can be designed to actuate switch units coupled to visual or audio devices which provide warning when limiting speeds are reached. The MASI can also be linked to the auto throttle system so that commanded airspeeds are maintained. In modern airline aircraft, the MASI is superseded by the Air Data Computer which provides airspeed and Mach number inputs to the Flight Man