Avionics Technology

B31353551

— *Inertial Navigation*

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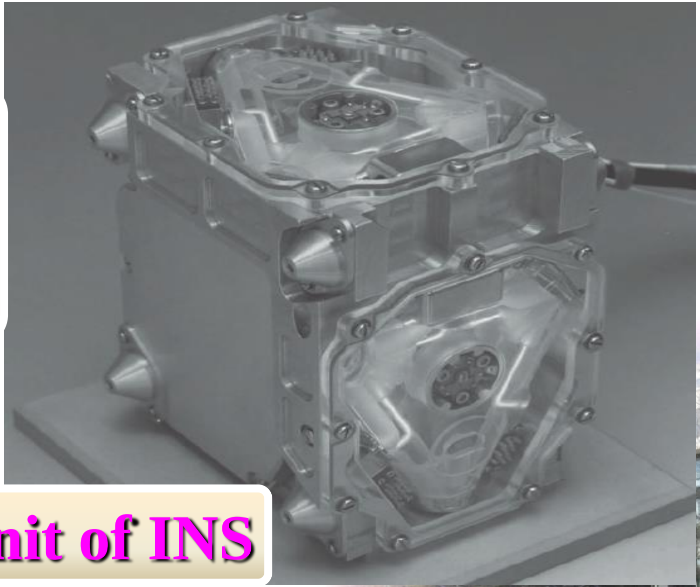
IV. Inertial Navigation

References and further readings —

The first half part of Chapter 5: *Inertial Sensors*, § 6.1 and § 6.2 of Chapter 6: *Navigation Systems*, *Introduction to Avionics Systems* (2nd Edition).

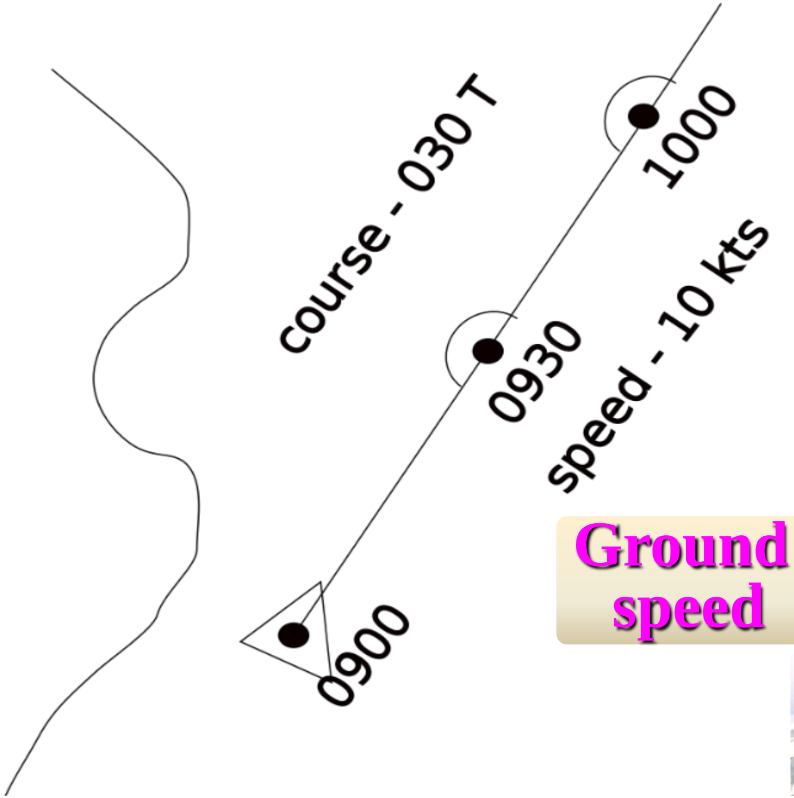
INS: Inertial navigation system



Computing unit of INS

Measuring unit of INS

- If we knew where we started, in which direction we were pointing and the speed of motion in this direction, then we can determine our position at any instant in time.



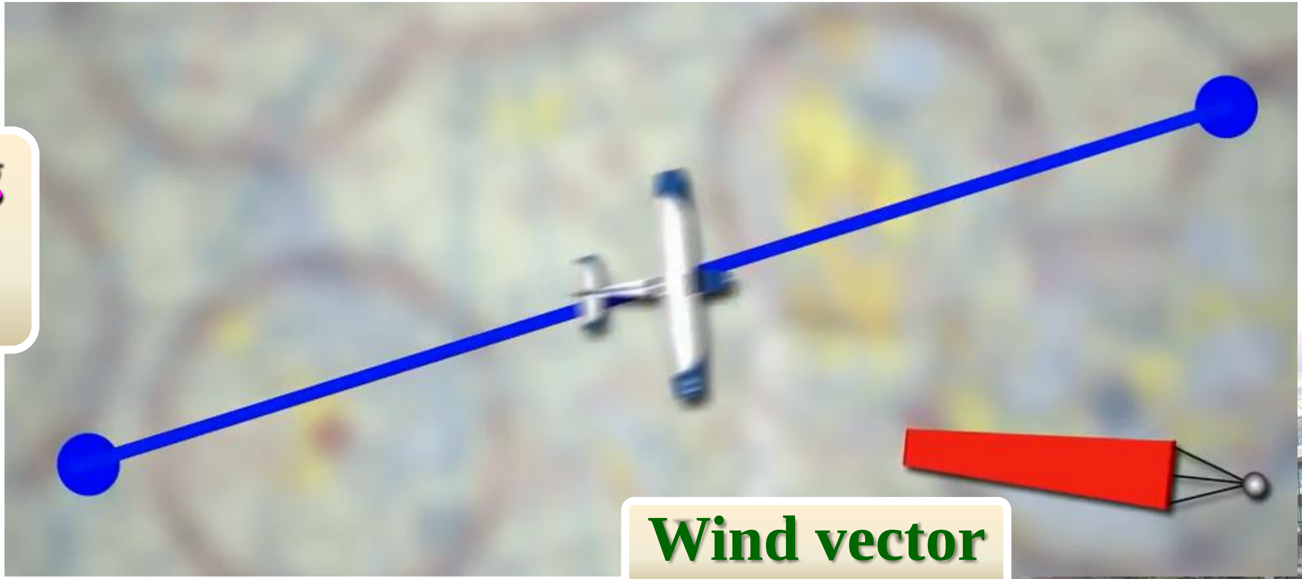
Ground speed

***Course*: Intended horizontal direction of the route**

IV. Inertial Navigation

- Such a navigation method can be achieved by utilizing some basic information: the true airspeed, wind speed and direction (forecast or estimated) and the aircraft's heading.

A change of heading is required to hold the course



IV. Inertial Navigation

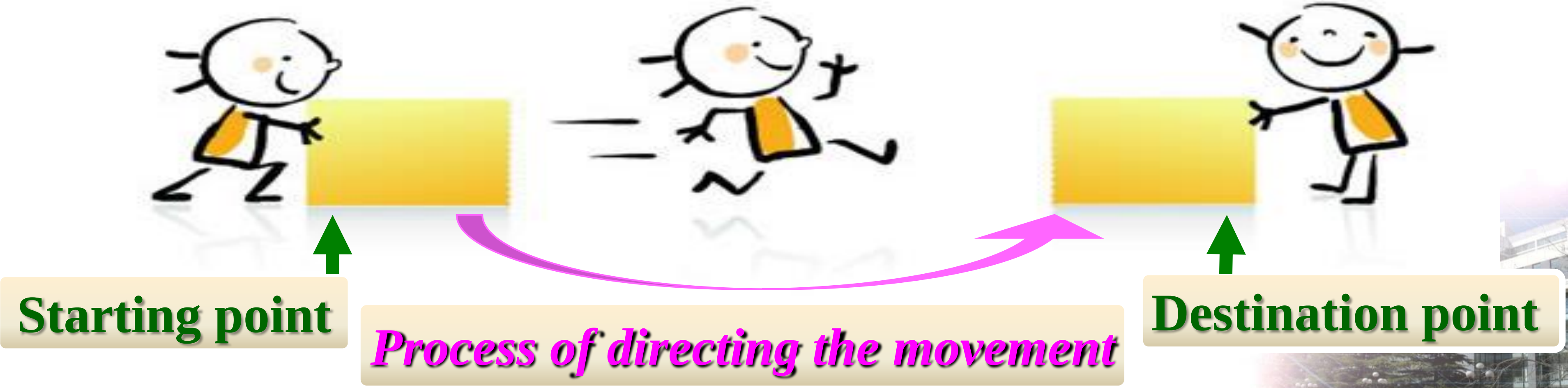
（1）Some concepts

（2）Accelerometer

（3）Inertial navigation

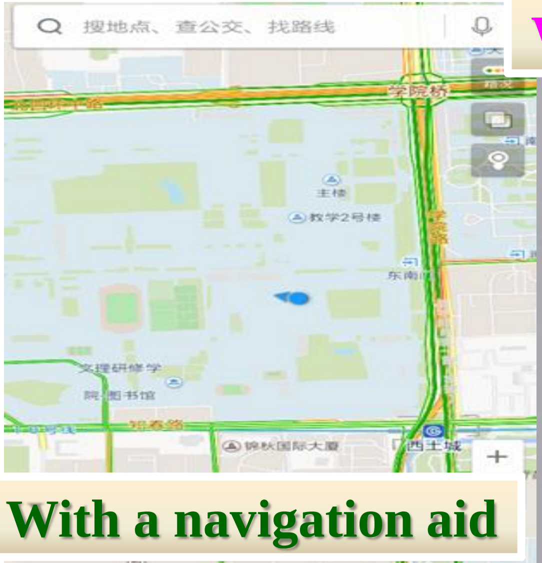
（1）Some concepts

- *Navigation* is the act, science or art of directing the movement of a ship or an aircraft.
- Navigation thus involves both control of the path of movement and the guidance for arriving at destination.



（1）Some concepts

- We conduct some form of navigation in our daily lives, utilizing fundamental navigational skills, e.g. our eyes, common sense and landmarks. However, in some cases where an accurate knowledge of our position, intended course, and /or transit time to a desired destination is needed.



With a navigation aid

Without navigation aids

(1) Some concepts

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- High accuracy navigation systems are essential for civil transport aircrafts to fly safely in all weather conditions, including when the ground references are not available, in fog conditions, flying in cloud and night flying.

（1）Some concepts

- The density of air traffic on major air routes requires the aircraft to fly in a specified three dimensional corridor or ‘tube in the sky’. And the aircraft must follow a fourth dimension, i.e. time, corresponding to a specified time slot.

A highlighted flight on its air corridor

(1) Some concepts

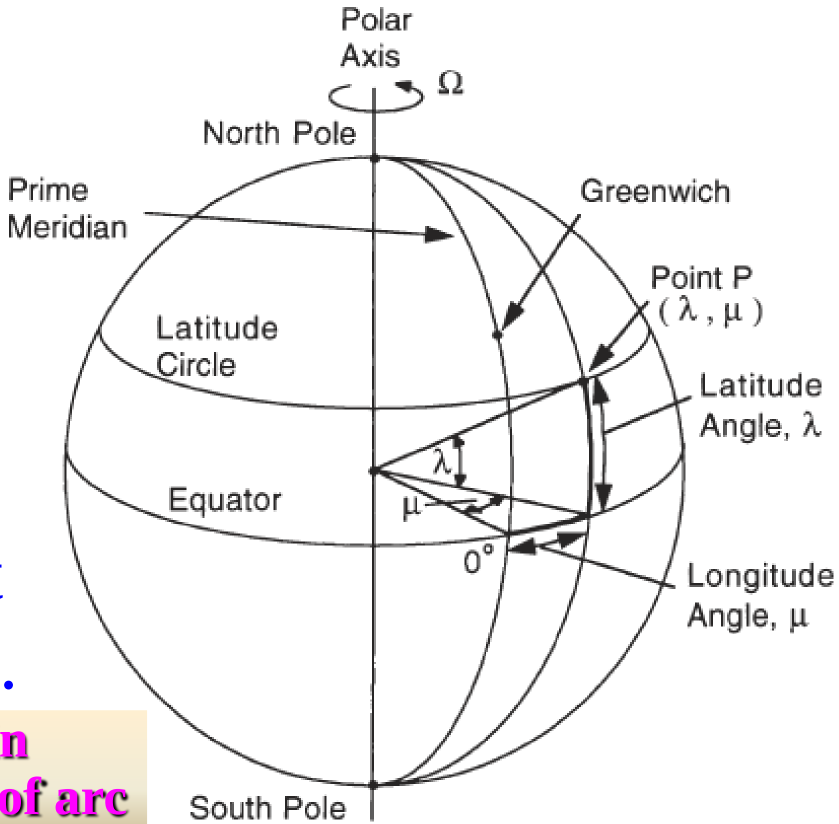
- A civil aircraft’s position in terms of its latitude / longitude coordinates, ground speed, track angle, altitude and vertical velocity are equally essential for the navigation of the aircraft.

***Track (angle)*: Direction of the ground speed vector relative to true North**

Aircraft in the Earth’s reference frame

(1) Some concepts

- Position on the earth's surface is generally specified in terms of *latitude and longitude coordinates* which provide a circular grid over the surface of the earth. The Earth is basically a sphere, de facto ellipsoid, and the variation in the radius is taken into account in the navigation computations.



Latitude / longitude expressed in degrees, minutes of arc and seconds of arc

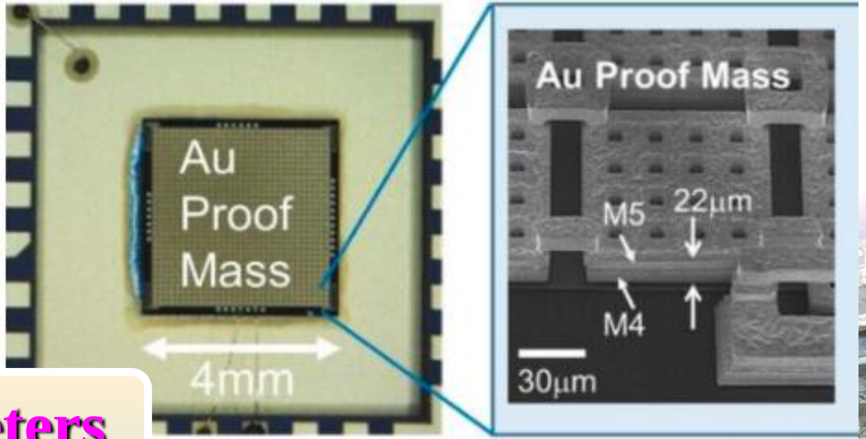
(1) Some concepts

- The shortest distance between two points on the surface of a sphere is a *great circle* (great circles are circles on the surface of a sphere with their center at the center of the sphere), hence navigation routes for civil transport aircrafts try to follow a great circle path.

Busy air routes of civil aviation

(2) Accelerometer

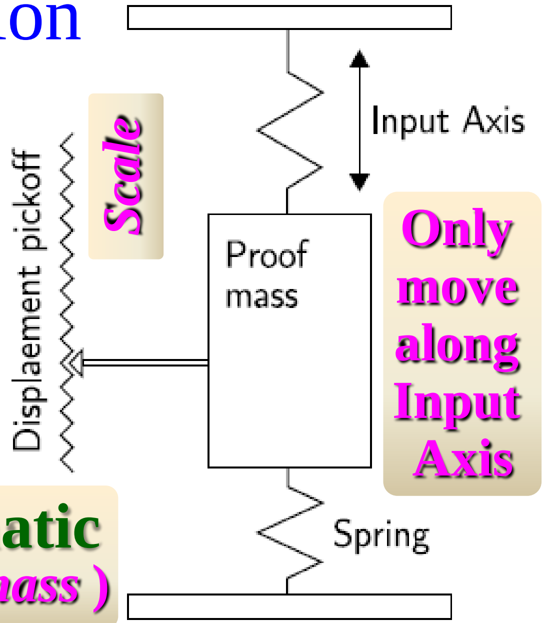
- Accelerometers are known as inertial sensors, which exploit the property of inertia, to sense changes in linear motion, i.e. measure the linear acceleration.
- Gyros and accelerometers are the essential elements of the inertial navigation system (INS).



Different types of accelerometers

(2) Accelerometer

- The accelerometer consists of a proof mass restrained by springs. The displacement of the mass is measured using a displacement pick-off, giving a signal proportional to the force acting on the mass in the direction of the input axis. Newton's second law ($F = ma$) is then used to calculate its acceleration (the same as that of the aircraft on which the accelerometer is suspended).

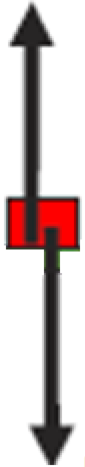


Mechanical accelerometer schematic

measuring the *specific force* or (*force/mass*)

(2) Accelerometer

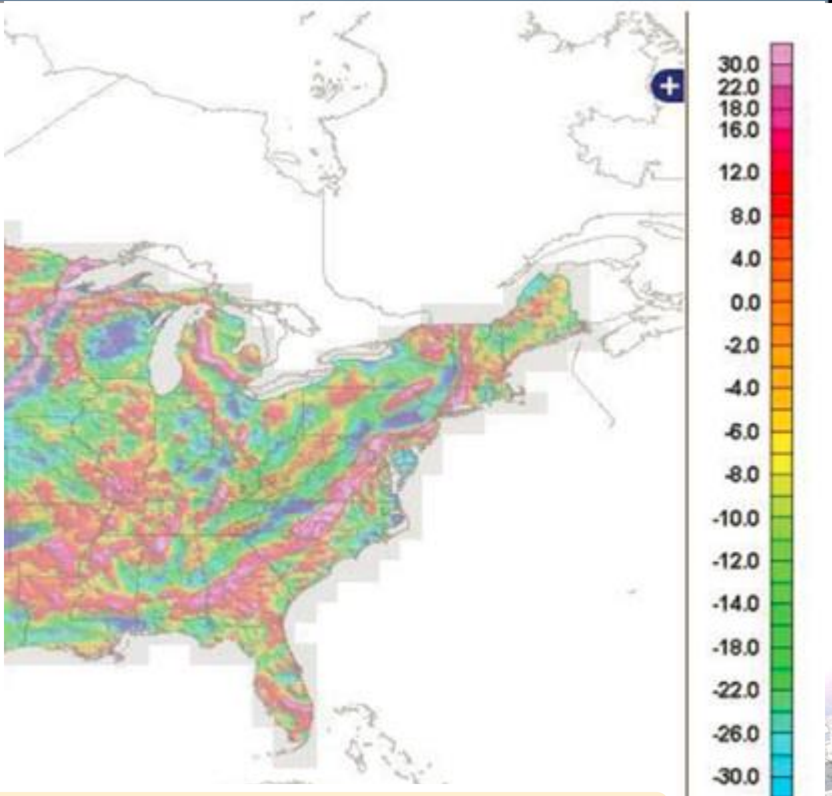
- This measurement is complicated by the fundamental fact that it is impossible for the accelerometer to distinguish between the force acting on the roof mass due to the Earth's gravitational attraction and the force required to overcome the inertia and accelerate the mass so that it has the same acceleration as the aircraft.



If the accelerometer input axis is coincident with the direction of gravity force, then the output of the accelerometer will ≈ 9.8 m/s^2

(2) Accelerometer

- Gravity is not constant (anomalies), doesn't always point to the center of the Earth, and varies as a function of altitude. It is thus essential to know the magnitude and orientation of the gravitational vector with respect to the input axes in order to compute the acceleration components.



Gravity anomaly map
1 mGal (milli-Galileo) = 10^{-5}m/s^2

(2) Accelerometer

- In addition, an accelerometer detects only the component of the resultant acceleration of an aircraft along its sensitive axis (input axis), and has no way of telling whether the detected velocity change (i.e. acceleration) is due to a speed change or a direction change or both.

Direction of the motion changes and therefore the velocity changes

(3) Inertial navigation

- We can sense the aircraft’s acceleration (and also the gravitational vector) with accelerometers. If the acceleration components are then derived along a known set of axes (relying on gyros), successive integration of the acceleration components with respect to time will yield the velocities and distances travelled along these axes.

Inertial navigation schematic