AGI Article
Published in Air traffic Technology International 2010

This or That
Runway Visibility a discussion

Calculating the runway visibility range is a straightforward application, however there is still a debate on the best instrument to measure visibility. This article sets out the issues and choices between a Transmissometer and a Forward scatter instrument to calculate runway visibility.

Up to the mid 1990s there was only one proven way to measure visibility, using a Transmissometer. This situation changed when the FAA published the results of a trial comparing forward scatter meters with transmissometers. They published their results in 1997 and since that time there have been other studies that broadly match the FAA results. In short the FAA and other studies have proved that forward scatter sensors offer a similar performance to transmissometers but there are marked differences and it is these differences that are put into context in this article.

Before the differences are set out, it is of value to understand the principles of operation with both instruments and to understand what visibility means and how it is measured.

Visibility

Horizontal visibility through the atmosphere is determined by the presence of particles which cause light to be scattered. For light in the visible and near visible part of the spectrum, scattering occurs by suspended particles such as fog droplets, dust and smoke particles. Scattering also occurs with raindrops, drizzle droplets, snowflakes and hailstones.

Scientifically these effects are quantified and the term extinction coefficient is given to the measurement of visibility. As one might assume, on clear days the extinction co efficient (EXCO) will be low, but high on occasions where there is dust or high amounts of moisture present. . Without going into the theory, another measure of visibility is called the Meteorological Optical Range (MOR) and it is a direct function of EXCO.
Learned people and the World Meteorological Organisation (WMO) produced a mathematical formula that enables instruments to measure visibility and using this formula to calculate MOR. The two methods of measuring visibility use either a transmissometer or a forward scatter meter

Transmissometers

A Transmissometer (TMX) measures the transmission of a reference light beam and compares it with a beam of light that has travelled a specific distance through the atmosphere where it will be attenuated due to the particles scattering and absorbing the light. By knowing the distance the light transmitter and the light receiver are apart and measuring the attenuated light with a photodiode, the resultant measurement is called the total extinction co efficient. Transmissometer measurement distances vary from 20m to 75 m.

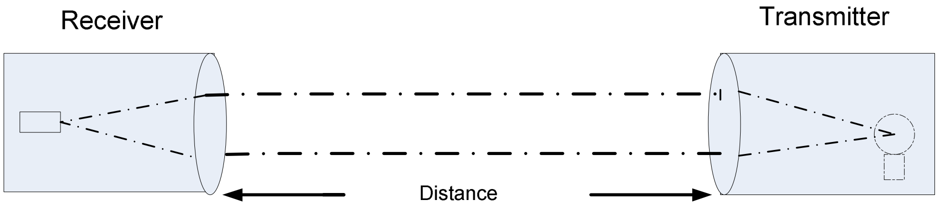

Figure 1 Transmissometer outline

Forward Scatter meters

Forward scatter instruments (FSI) measure the amount of light scattered by the suspended particles at angles less than 90 degrees passing through its sample volume.
The sample volume is defined by the intersection of the transmitted beam of light and the ray cone, which defines the field of view as shown in the diagram below.

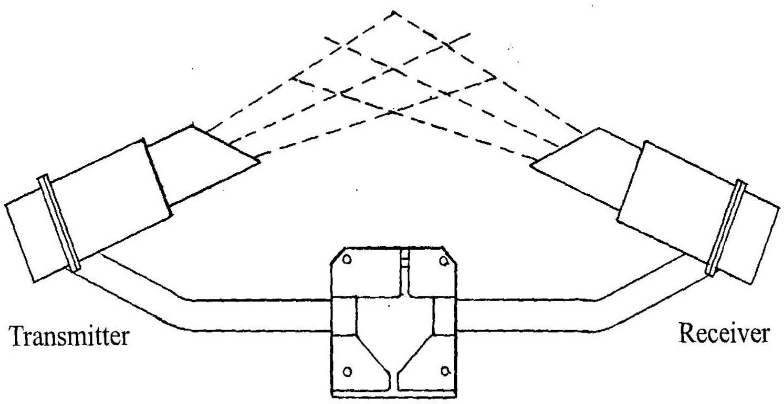

Figure 2-1. Top view of the Sensor Head.

Figure 2 Forward Scatter instrument layout

As shown in Fig 1 a transmissometer basically consists of a light source, the transmitter and a receiver a photodiode, separated by a distance. Manufacturing is not complicated but there are issues, particularly the cleanliness of the optics to ensure that the receiver and the transmitter are always operating efficiently. It is critical that the windows are kept clean or there is an electro optical system to detect dirty optics and compensate for this at the receiver.

Compare this to Fig 2 where many facets of the construction of an FSI affect its performance. The FAA discovered that the critical dimensions were:

- ❖ Transmitter beam geometry
- ❖ Receiver beam geometry
- ❖ Average scattering angle.

In addition electronically,

- The transmitter light intensity
- The receiver gain.

Variations in these parameters affected the output of the FSI. On this basis the FAA concluded that the only way to prove FSIs were to compare them with known TMXs. These tests were carried out by the FAA and they proved that in all weather conditions both a TMX and a number of FSI systems produced comparable results.

Runway Visibility

Runway visibility is one of the key parameters that a pilot requires before landing the aircraft.
The RVR definition from the International Civil Aviation Organisation (ICAO) is as follows.
RVR is the range over which the Pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line."
At the eighth air navigation conference held in Montreal in 1974 this definition was modified to read "RVR cannot be measured directly on the runway an RVR observation should be the best possible assessment of the range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line.
The key statement that stands out is the best possible assessment.

To provide a runway visibility reading, two methods are used.

- A Human observer who determines runway visibility by observing the runway lights.
- An Automatic measurement either using a Transmissometer or a Forward Scatter meter.

Figure 3 Runway lights at dusk

Before automation RVR was determined by a human observer. The job entails standing on a platform adjacent to the runway touch down zone and counting the number of opposite side runway edge lights visible from the observation point. As air traffic has dramatically increased over the last 20 years and radar technology has enabled take off and landings in almost zero visibility, human observers both from a safety angle and with air traffic volumes are unable to cope with the task.

Automated RVR measurements using a computer need two other parameters, the brightness of the runway lights and the ambient light (or lack of it.).
Background Luminance is measured using a photodiode viewing a portion of the north sky to determine the ambient light level.

The runway lighting value is a measure of the amount of current taken by the runway lights. The settings are at 1%, 3%, 10%, 30% and 100%

Each of these parameters has an associated error. A respected meteorologist Dr Alan Hisscott has investigated the use of FSIs and carried out a number of trials in the early 1990s on the Isle of Man. Dr Hisscott has written and presented a number of papers to the Royal Met Society concentrating on the scientific comparison of TMX and FSI performance. From his trial results he has quantified the errors in each of the RVR parameters.

The luminance parameter is certainly influenced by the ambient airport environment.
From a trial of forward scatter sensors in 2001, Dr Hisscott noticed a difference in luminance values between two identical background luminance monitors (BLM) located at different parts of the airport. With no change in visibility Dr Hisscott deduced that the difference in the two sensors was caused by the runway lighting.

It is evident that taking five specific values for the runway illumination must also introduce errors into the RVR assessment and both Dr Hisscott and others estimate that the runway lighting value could be in error by 50% due to lamp aging and contamination. His assessments on the scale of the errors were as follows.

Parameter	**ΔRVR**
Runway Light intensity	10%
Background luminance monitor	6%

A further issue that affects both TMX and FSI systems is the build up of contamination on outside glass window surfaces of the sensor and light transmitter housings. Most TMX and FSI RVR systems have additional sensors and software to detect window contamination, which is used to provide an automatic correction. In this way contamination can be managed, but it is a factor that will be different with each installation and airport. These other error factors outweigh the differences between a TMX and FSI measuring visibility.

Referring back to the FAA study their conclusion was that the way to compare FSI and TMX systems was via a reference using a known calibrated TMX system. At operating airports the visibility problem that causes all the problems is Fog.

Fog can be a transitory event and both the FAA and other recent trials by both AGI and the German Meteorological Service (DWD) have shown that the major difference between forward scatter sensors and transmissometers is the detection of transitory or inhomogeneous fog.

AGI RVR Comparative tests of a Transmissometer and Forward Scatter

In order to prove a forward scatter sensor (the Biral VPF 730) AGI carried out a trial at Birmingham airport between an AGIVIS 2000 system and an AGI FSI RVR system. The AGIVIS 2000 has been in operation for over 20 years and has proved its accuracy and reliability both in bench mark trials and in operational use. The trial data was analysed by Dr Alan Hisscott as well as other mathematicians.

Dr Hisscott's analysis of the data captured during fog periods are set out below.

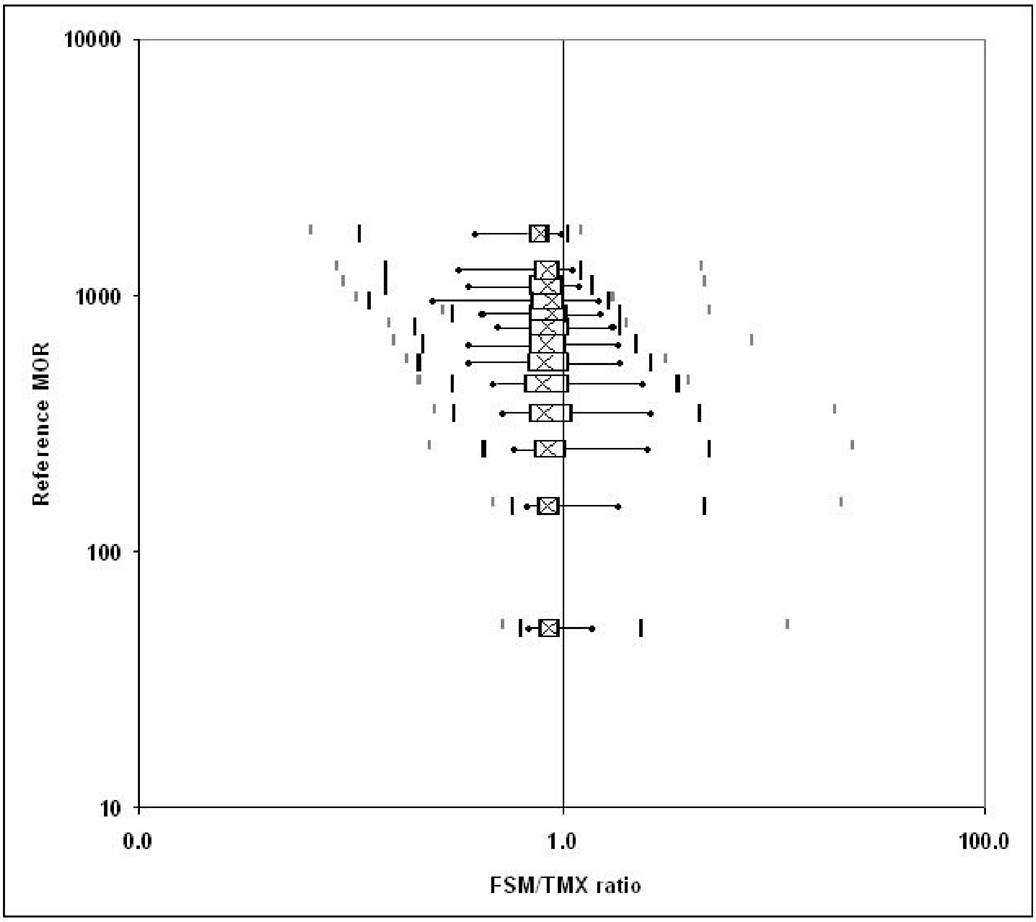

Figure 4 Box plots of data gathered in Fog

The difference between the complete set of values and those set out in Figure 4 suggests that the apparent increase in the forward scatter system MOR in the region 1000-1500m, arises from the instruments having a different response to transient conditions. MORs in this range often corresponds to transition visibilities during fog formation and dispersal. The difference between the AGIVIS 2000 and the FSI system is probably fundamental to their design. The volume of atmosphere sampled by a Transmissometer (say 10m beam length x 0.05m^2 X-section = 500 litres) whereas FSM sample volume is usually around 3 litres. Also, the geometry of the sample volume is very different. During the formation/dispersal process of fog there are large spatial variations in droplet density over small ranges. The TMX beam has a higher probability of 'capturing' one or more 'wisps' of inhomogeneous fog during a measuring interval than the smaller sample volume of an FSM. However, it is likely that during such transient conditions neither instrument can measure an MOR sample which is truly representative of conditions along a runway.

The most important part of the RVR range for Cat I operational decisions is around 400-800m and the average median ratio in this range is 0.83 i.e. the FSM reports MOR around 17% less than the TMX in this range. Although it is possible to modify the calibration of FSMs to match the median of the TMX, my view is that, at this stage of adopting FSM technology, it is probably better to retain the 'safe' bias where around 75% of the FSM MOR measurements are equal to or less than the equivalent TMX MOR.

Dr Hisscott's conclusions were as follows:

- A median difference in MOR between the Transmissometer and the Biral sensor was -13%
- This is consistent with the other errors in IRVR calculations.
- <u>The type of sensor used to measure the MOR does not contribute a more significant error than the overall error arising from the other parameters.</u>

Summary

It is the transitory nature of fog particularly during formation and dispersal that causes the major differences in output from an FSI system and a transmissometer. In Europe and some other countries forward scatter systems are only used in small regional and Cat 1 airports. The actual comparative data when fog is well formed and thick is very comparable. This was also proved in the DWD trial as set out in their paper by Stefan Waas.

"In general measurements of forward scatter sensors and transmissometers match very well in homogeneous conditions especially at visibilities below 1000m.
"During inhomogeneous visibility conditions even transmissometers can differ very strongly in direct comparison to each other."

The advantage that FSI systems have over TMX ones is their price and simplicity. The other differences are set out in the table below.

Parameter	**TMX**	**FSI**
Base mounting	Solid concrete foundation	Simple fix in soil
Number of sensors to calculate the required visibility	Two to cover the range 10m 10km	One
Calibration	Only in clear visibility	Any time with the calibration plate
Window contamination detection	Critical components to ensure accuracy	Not as sensitive to window contamination

The other concern over FSI sensors is the repeatability or consistency between sensors. As the FAA trial found, it is critical that FSI sensor dimensions are consistent from sensor to sensor. This is dependant on the quality and design of the sensor.

References

1. United States Experience Using Forward Scattermeters For Runway Visual Range DOT/FAA/AND-97-1 DOT-VNTSC-FAA-97-1 by David C Burnham, Edward A Spitzer, Thomas C Carty, Deborah B Lucas
2. Stefan Waas German Meteorological Service Field Test of Forward Scatter Visibility Sensors At German Airports
3. Dr Alan Hisscott Isle of Man Meteorological Office Ronaldsway An Evaluation of Forward Scatter meters for IRVR (CAT 1 Precision Approaches)