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Optical and Structural Developments in Air Traffic Control Tower Glazing

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Abstract

With about 4,500 medium and large airports around the world, Air Traffic Control Towers (ATCT) are essential elements of our transport infrastructure. Safely orchestrating air traffic requires a perfect visibility of aircraft in all weather and lighting conditions. Aviation being a conservative field, towers are built or renovated using decades-old technologies, with disappointing results. Design parameters can be grouped in five categories: structural, blemishes, insulation, photometric and optical. Transcending country borders and traditions, we will detail each of these groups and explain the newest technical solutions available. This paper can be used as a checklist or design guide if you need to conceive an ATCT or other structures, such as an indoor observation deck or high-end retail storefront, where vision is paramount. Special attention will be given to visual distortion in transmission, haze, anisotropy, double image, reflection management, electrochromic, and glass-to-glass connections.

Keywords

Visual distortion, haze, anisotropy, double image, reflection, solar heat gain.

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1. The importance of ATCT and traffic management

The collision of an A350 with a coast guard plane at Tokyo Haneda Airport is a recent example of the importance of air traffic control. In this case, all 379 occupants of JAL flight 516 survived but 5 out of 6 passengers of the smaller aircraft died.

Each aircraft on the tarmac contains 100-400 persons and there is no place for error. All information must be validated by the controllers and manual backup systems are always kept up to date. On-screen information from radar systems must be visually corroborated and in sync with the small blocks that are lined up in front of the controller. Moreover, in the larger tower, that set of information must be passed over a second and a third controller as each one monitors a specific section of the runway and taxi lanes.

ATCTs are installed on very tall structures. The highest is the Vancouver Airport at 146 m. These single-purpose buildings are expensive to build. A recent project I worked on was 110 m high and cost about 50 M USD to build. Considering the costs involved, it is well worth to spend money on the glass used!

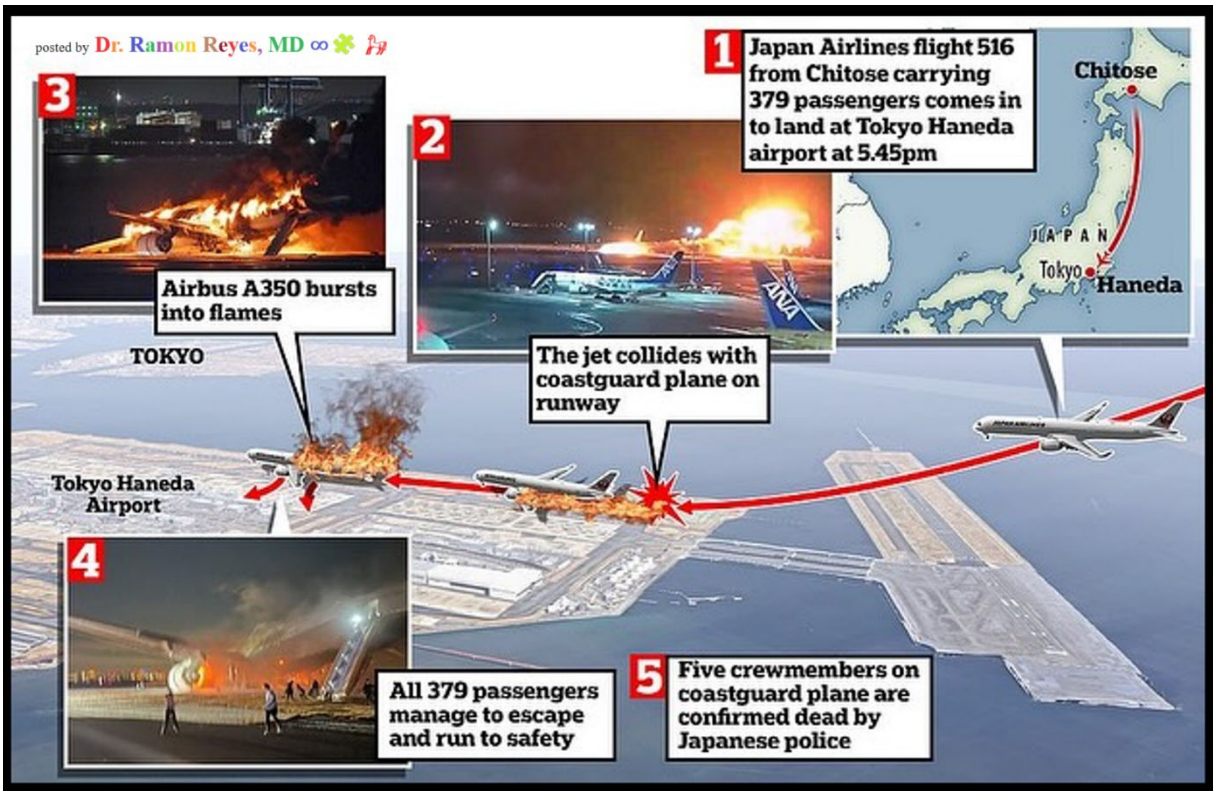

Fig.1: Collision in Japan – Reuters.

2. Existing Standards and Guidelines

Around the world, France’s “Service technique de l’Aviation civile” published the most comprehensive publicly available documents on ATCT design. The five “fascicules” (Département Bâtiments, 2007) cover most aspects of ATCT design, from where to locate the tower to the glazing properties. These documents were published in 2007. Since then, progress in glass, interlayers, and measuring equipment brings more resources for the engineers.

ASTM E2461 (ASTM 2022) is another useful standard, but it is limited to the wind load calculations of trapezoidal glass. It was recently refreshed with more complex glass configurations.

3. Structural

3.1. Location

The key element in ATCT remains visibility. The tower position must ensure complete visibility of incoming airspace, runways, taxi lanes, parking space and outgoing airspace. This can be a challenge when airports have several runways and many terminals!

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Fig.2: Chicago O’Hare International Airport – Google Maps.

When Chicago O'Hare International airport (ORD) added new runways to accommodate the new A380 in 2013, they complexified their network and needed to build a second tower. That new tower was my debut in the North American ATCT market, producing eight 4.5 m X 2.7 m triple layers laminates with acoustic interlayer.

Once the location is chosen, there are critical points of view that all operators need to see:

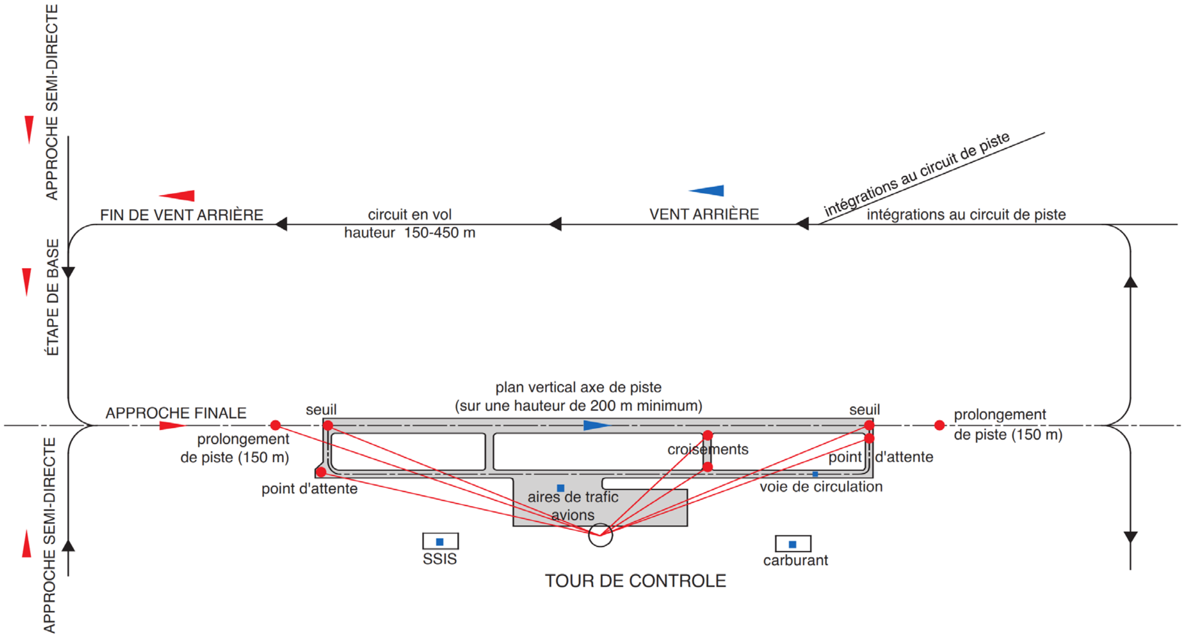

Fig. 3: Typical runway configuration – (Département Bâtiments, 2007).

These are the touchdown points at both ends of the runways, the runway holding positions and the connections to taxi lanes. Having small glass with multiple thick mullions can be visually challenging for controllers. Fortunately, developments in stiff interlayers allowed to increase the glass sizes and even eliminate the vertical mullions by providing a top and bottom support only. This was done in the Sarasota, FL ATCT, inaugurated in 2017.

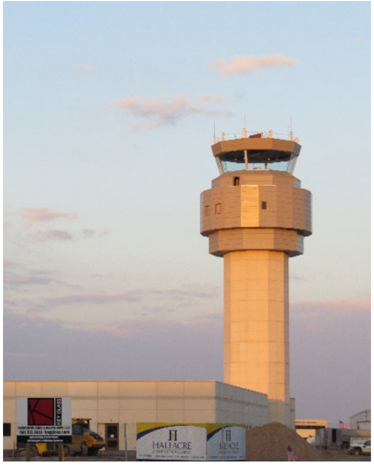

Fig. 4: Sarasota, FL ATCT – Key Glass.

Fig. 5: Sarasota Installation – Key Glass.

Fig. 6: Sarasota panoramic inside view – Author.

3.2. Glass to glass connection

When working with top and bottom supports, multi-layers laminates with stiff interlayers are useful, especially when using annealed glass. Care must be taken to minimize the haze associated with ionomer interlayers. In Sarasota, stiff PVB was used, as its short-term stiffness is comparable or even superior to ionomer, without worry about haze.

Finite Element Analysis (FEA) is greatly encouraged to predict movement and stress on all components. Lastly, mitering the verticals of glass elements allows narrow structural silicone joints.

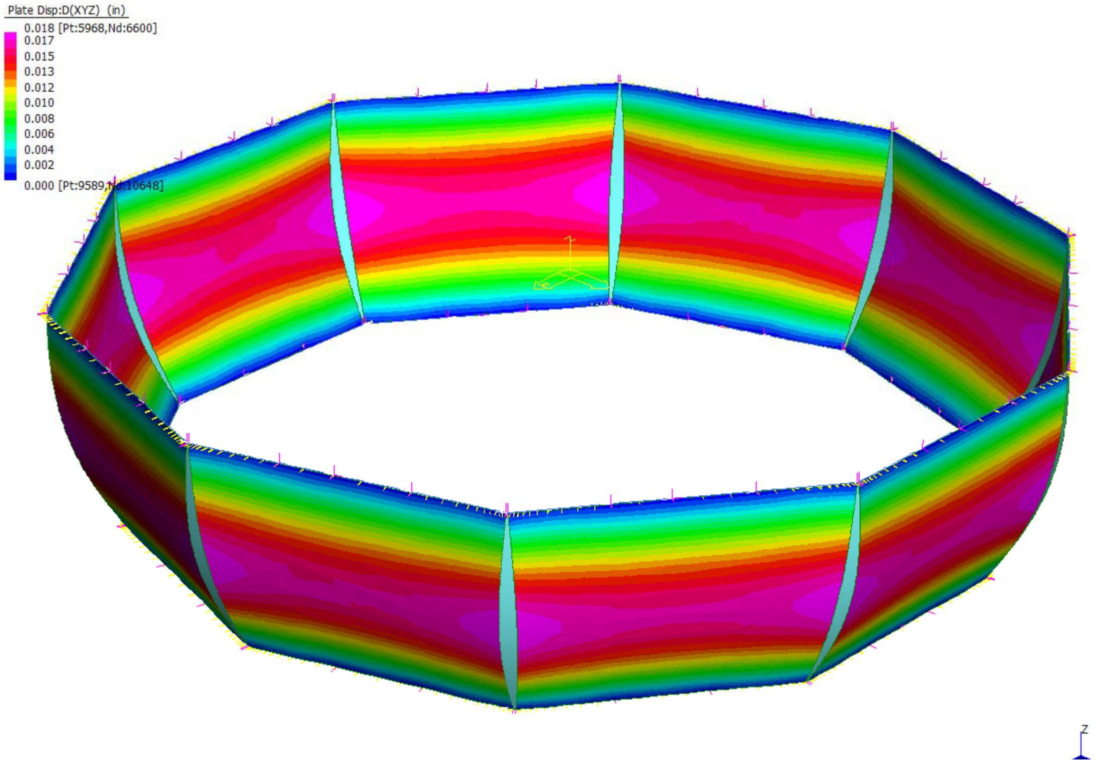

Fig. 7: FEA Analysis deflection – Eckersley O'Callaghan.

4. Blemishes

Blemishes (ASTM) or Faults (EU) are defects found in the float glass, created by mechanical contact, created during lamination or deposited on the surface in non-accessible areas.

The ASTM 1036 and EN 572 standards give very useful guidelines on how to inspect and qualify blemishes. They provide tables on acceptable size, quantities, and distance between defects. Unfortunately, for point blemishes, they measure the defect's halo or distortion. This creates ambiguities in interpretation of acceptable size. We prefer to work with a USB calibrated microscope and measure the defect itself. This allows us to take a picture of each defect with size close to the allowable dimensions, and it is also possible to superimpose a measurement ruler on these photographs.

ASTM C1036 Table 2 states values for 6 mm or less glass. For heavier thicknesses, a ratio must be applied. It applies to each component of the finished product. Thus, it is possible to have defects that are very close together if they are in different layers of the final assembly.

When specifying a quality level for ATCTs or other visually critical applications, we specify the allowable defect size for the whole assembly (all layers). As bubbles in glass and bubbles in PVB are similar, we amalgamate all defects into that table. We also define viewing zones that can have different defect size and density. This eliminates a lot of ambiguities when inspecting glass on site or in the production plant.

5. Insulation

ATCTs are sealed buildings exposed to the elements. They rely on air conditioning to keep the controllers in comfortable temperature. Often, this creates a temperature differential that can lead to condensation. We will see the different strategies used to prevent condensation.

The towers being solo in the field, exposure to sun leads to important Solar Heat Gains (SHG). The traditional way to minimize this energy gain was to use a tinted substrate, leading to reduction not only in SHG but also Visible Light Transmission (VLT) and colour rendering index. Modern double and triple silver coatings can maintain a high VLT while drastically reducing the SHG and keeping a neutral colour in transmission.

ATCTs being very close to noisy operations, acoustic insulation represents an important design factor. Acoustic interlayers are an easy way to improve results. In Chicago O'Hare's ATCT, we used acoustic interlayers in the triple laminate.

Electromagnetic shielding in the glazing was an important feature in the early ages of computing. In the 70s and 80s, radar technology used intense bursts of radio waves and computers were sensitive to them. Today, arrays of radars are located farther away from ATCTs and they produce 3D positioning of aircraft using a weaker signal. Electronic equipment has also been better ruggedized to resist EMI. Thus, today, electromagnetic shielding is limited to maintenance of vintage ATCTs with older or poorly located radars.

5.1. Condensation

Outside morning condensation has always been a challenge for monolithic glazing. In the 70s, electrically heated laminates were developed. They used a fine wavy tungsten wire embedded in the PVB to warm the glass and prevent condensation. Their installation was complicated by individual electrical connections and the need for specific voltage to match the panels' resistance. The connections, wiring, and control system proved to be complicated to maintain.

In the United States, the Federal Aviation Administration (FAA) opted to use sprinklers that spray water on the outside of their monolithic glazing when condensation appears. This requires a lot of infrastructure and maintenance to deliver demineralized water on top of the ATCT. The new Sarasota, FL ATCT still uses that system.

Insulated Glazing Units (IGU) proved to be easier to implement but introduced other challenges by raising the interior reflection and introducing double image risks. They provide a better temperature gradient and are effective in preventing condensation in most climates. The use of low-emissivity coatings and argon will also increase the insulation value (U value) of the IGU.

5.2. Solar Protection

The use of high-performance coatings allows for lowering the SHG while maintaining a higher level of light transmission. Unlike tinted glass, they do not absorb as much heat and can be used in annealed form. In all instances, a thorough thermal breakage risk analysis needs to be performed. Vitrages Décision is the only software that incorporates a thermal breakage risk calculation module. Examples of compositions will be discussed in the photometric properties section.

5.3. Sound Protection

Aircraft takeoff can produce sound levels near 125 dBA. In a multi-runway airport, this creates a high ambient noise level around the ATCT. In a recent project we worked on, the equivalent level LAeq day at the tower was 65-70 dBA. And the maximum noise was LAmax 90 dBA.

FAA studied the noise in the air traffic control tower (Semmelink, 1971). Although the document sets no limits, it cites other studies indicating a value of 50 dBA as a satisfactory level for telephone use and for personnel who must use voice communication. At 55 dBA communication becomes slightly difficult and at 70 dBA telephone and face-to-face communication becomes difficult.

We found that Australia has set a maximum noise level inside ATCTs of 50 dBA (Australian Standard AS 2021, 2015). This value is in concordance with the FAA study.

Using the Australian standard in the project studied meant that the glazing had to offer an attenuation of:

$$LAmax\ \ 90\ dBA - 50\ dBA\ int = Rw\ 40dBA \tag{1}$$

The main methods to achieve good attenuation levels in glazing is to use thick glass, asymmetrical glass composition in IGUs, and/or laminated glass – preferably with acoustic interlayers. Another technique uses a wide cavity in IGU. However, this should be avoided in ATCTs as it can lead to double images when the large gap warms and compromises the parallelism of the glass. A good trade-off for the gap is between 10 and 12 mm.

In a double-glazed unit, the maximum sound attenuation that can be reached is around 50 dBA. This requires a double laminate with acoustic interlayers configuration.

6. Photometric Properties

6.1. Light transmission

Although it is one of the most important characteristics of the glazing, there is no consensus in the literature about an ideal value. It remains a compromise between day and night vision. In the FAA document “Air Traffic Control Tower Cab Glass Evaluation, Specification and Assessment with Respect to Optical-Visual Characteristics” (Task, 2007), a minimum value of 65% VLT is mentioned in paragraph 5.1. The current trend in ATCTs in the USA is to maximize light transmission to enhance the night vision and use a shading system to cut the light level and glare during daytime.

The shading systems used are usually very dark transparent films with a VLT <5%. On its website, the company Plastic-View claims, “Over 98% of all U.S. ATCTs, both civil and military, have received our shades.” These films are cut to fit the window shape and are motorized to simplify their use. As they are made of polyester, they are easily scratched and are difficult to clean when they become dirty.

The developments in electrochromic glazing are promising as their dynamic range matches the ATCT requirements. However, to our knowledge, they have never been used, because of their limited sizes, the need for trapezoidal shape and their clear-to-dark transition time.

6.2. Light Reflection

Light reflection is very important for night vision. An uncoated double-glazed unit reflection is approximately 14%. If glazing were vertical, at night, the controller would see a reflection of themselves and the control room. That is one of the reasons that ATCT glazing are slanted 15°-20° outward. The inside reflection is bounced to the ceiling that is usually painted black. Also, the light level is kept at a minimum inside the control room.

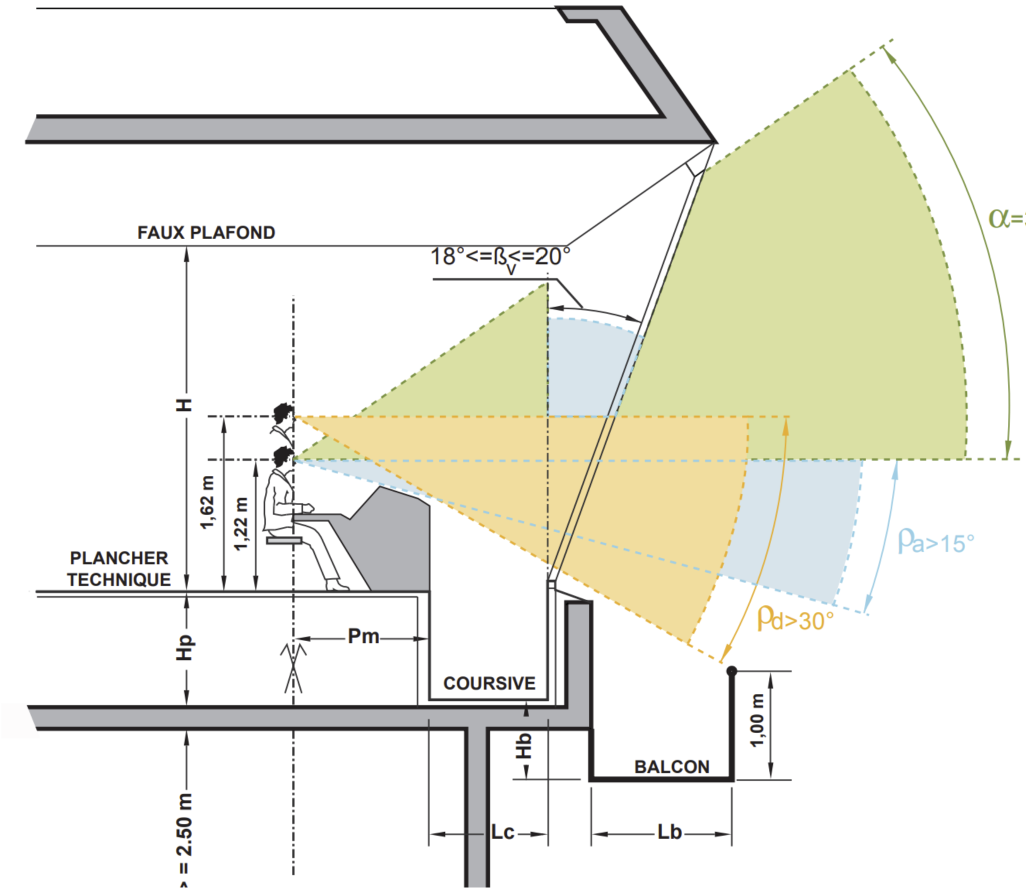

Fig. 8: Cross section of the Control room - – (Département Bâtiments 2007).

Sputtered anti-reflective (AR) coatings are commercially available in Europe jumbo sizes (6,000 mm X 3,210 mm) for the last decade. Their performances now rival the museum quality anti-reflective that were produced by dipping process. Understanding that reflection is created at the interface of substances with different refraction indexes, one realizes that AR coating must be used between all air-glass surfaces. Therefore, to be fully effective, AR coatings need to be in position 1-2-3-4 of an IGU.

The law of conservation of energy states that energy can neither be created nor be destroyed. Therefore, all reduction in reflection translates in an increase in light transmission.

The first use of AR coating in ATCTs was in Schiphol Airport, Amsterdam, NL in 2002. IGUs replaced the electrically heated laminates that failed after 13 years of service. I remember looking at the Amiran laminates on the shop floor, it was a revelation! The Schiphol configuration could be improved by using a laminated glass on the outside lite. This would allow an AR coating on position 1.

6.3. Photometric Comparison Between Different Compositions

Table 1 shows that solutions used in different countries vary greatly in photometric performances. In my opinion, the last two compositions that use modern coatings offer the best performances: good light transmission, little reflection, low SHG, and good insulation. In a South American location, those make-ups were annealed, guaranteeing better optical properties.

Table 1: Various photometric characteristics use in ATCT

Type	Description	Visible Light Transmission VLT	Outdoor Reflection Rf	Indoor Reflection Rb	Solar Heat Gain SHGC	EN673 U Value	Color rendering index
Annelead Typical US Tower	12 mm ultraclear 12 mm 12 mm ultraclear	**82%**	**15.0%**	**15.0%**	**0.80**	**3.0**	**98.7**
Monolithic heating	6 mm green-12 mm clear 12 mm clear All tempered Heated with fine resistive wires	**67%**	**6.5%**	**6.5%**	**0.47**	**4.6**	**84.6**
Traditional green tempered	8 mm Clear - 8 mm Planitherm XN 10 mm Air 10 mm Planitherm XN - 6 mm Green All tempered	**61%**	**6.8%**	**6.6%**	**0.47**	**1.9**	**82.8**
Annealed with AR and solar control	10 mm Clarity - SN70 Acoustic 10 mm Air 66.2 Clarity Acoustic or 10 mm Clarity	**70%**	**2.6%**	**2.5%**	**0.35**	**1.7**	**91.5**
Annealed with AR and solar control	10 mm Vision-Lite-10 mm XTREME 70-33 10 mm Air 6mm Vision-Lite - 6mm Vision-Lite	**76%**	**3.3%**	**4.3%**	**0.35**	**1.7**	**96.3**

7. Optical Properties

In this section, we will look at four characteristics that are often forgotten in specification but are of great importance in ATCTs and in other applications where perfect vision is paramount: storefronts, observation deck, etc.

7.1. Visual distortion in transmission

When heat treating or laminating glass, optical distortions are created. In an ATCT, these might generate deformation to the objects or to the plane path. This becomes very annoying to the controller.

In most specifications, roller wave will be specified in detail with peak-to-valley maximum values. However, these represent reflective distortion and when reasonable, they will not be visible in transmission. Lamination can also create distortion if edges are squeezed during the process or if there is a pressure point anywhere on the surface. This will create an annoying lens effect that can mislead the controller on the plane position.

In the architectural domain, the only standards that tackle the phenomenon are the ASTM C1036 paragraph 6.1.2 or EN 572 paragraphs 5.2.1 and 5.3.1. Here is the schematic of the simple but large setup that is used:

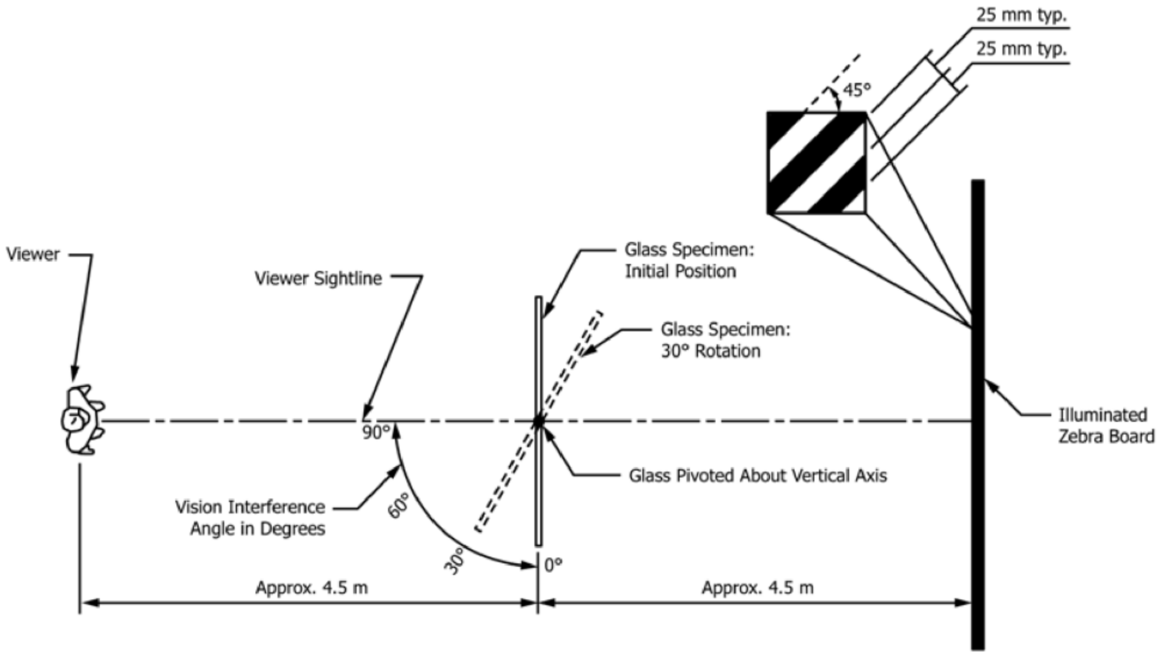

Fig. 9: ASTM C1036 Figure 2 – Setup for interference vision angle.

The allowable vision interference angle applies to the complete assembly (looking through the finished unit). Using a zebra board, the viewer rotates the specimen until they can perceive a distortion in the zebra pattern. For ATCTs, an angle ≤ 50-60° is desirable. Unfortunately, this test cannot be performed on site.

In the automotive world, the transmissive distortion is a strictly controlled parameter. In Regulation No. 43: Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles (United Nations, 2017), paragraph 9.2 describes an optical distortion test that works with projection. The author wants to study further this method as it might be easier to use on site and automate.

7.2. Anisotropy

Annealed glass, like water, is an isotropic material, meaning its properties are similar in all directions of observation. When glass goes through heat treatment (HT), its molecular structure is converted into that of an anisotropic material. Zones with different values of compressions are created because of non-uniformity in the heating and the cooling.

In most conditions, light is depolarized, with short-wave trains with an equal mixture of polarizations. Because of this mixed orientation, our eye does not perceive the mechanical deformation inside HT glass. However, if the light is polarized (direction of the light oscillation is perpendicular to the direction of motion of the wave in one plane) our eye catches the difference in the light speeds.

In this picture, we can see an alternance of light and dark zones. Those are the tempering oven signature.

Fig. 10: Anisotropy in an ATCT – Author.

In 2019, I led a task group to develop the first standard to measure anisotropy in architectural glass (ASTM C1901, 2021). This is a test method; it does not set limits. But it allows quantifying the level of anisotropy in a reference sample and can be used to objectively confirm that subsequent production is as good as the reference sample.

7.3. Double Image

Double image is an optical phenomenon that happens mostly in IGU when the two lites are wedged or you have a lens effect created between them. When using laminated heat-treated (HT) products, this phenomenon is more likely to happen. And it is what happened when the FAA was using EMI shielding glazing. Those were IGU with double HT laminates. The paper (Task, 2017) Addendum C explains the fundamental principle behind double image. It describes the “L” and dot tests that can be used to assess it.

Using different glass compositions can help hide the double image. In Fig. 11, I used Tasks’ equations to explain why green glass helped reduce double images. All compositions are 6 mm /0.76 mm PVB / 6 mm laminate. You can see that using a green layer lowers the double image intensity to 0,103% Vs. 0.160% for a clear laminate. However, using AR coating reduces it by two orders of magnitudes to 0.001%.

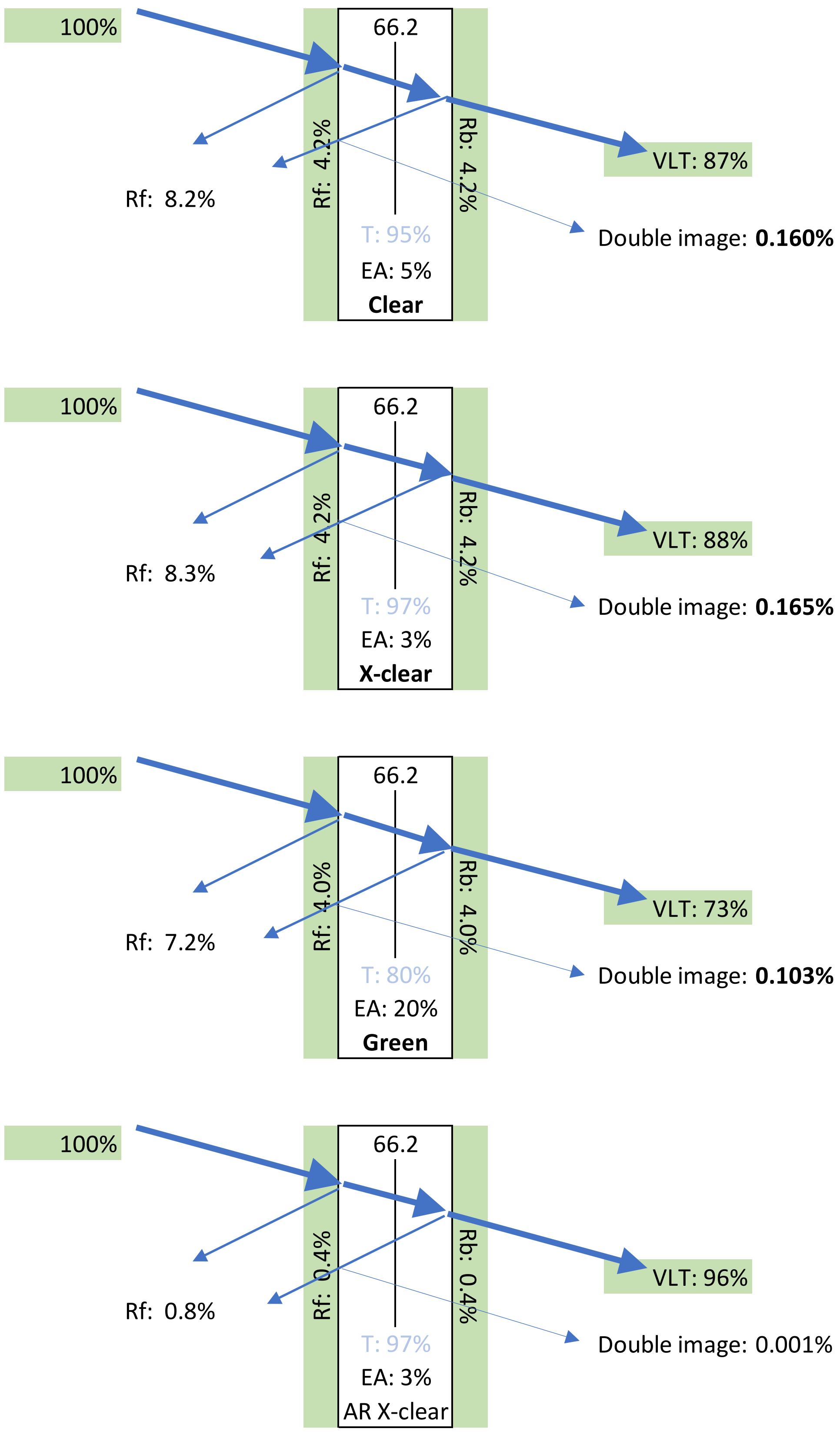

Fig. 11: Visible light transmitted, reflected and potential double image with various glass.

In the automotive world, the double image is also controlled. In Regulation 43 (United Nations, 2017), paragraph 9.3 describes two methods to evaluate it.

I found an instrument to measure the double image digitally. The SIAM is produced in Germany by Möller-Wedel.

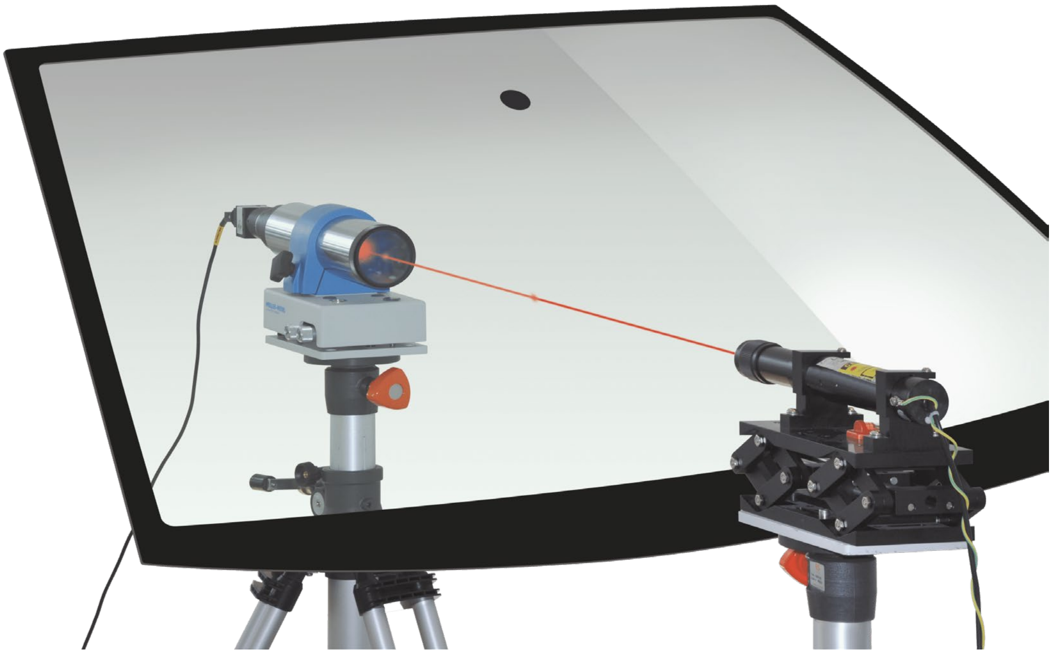

Fig. 12: SIAM, a double image measuring device - Möller-Wedel.

The author wants to further study this method as it might be possible to use it on site and automate.

8. Haze

Haze sources can be dirt or fine particles like smoke on the glass surface, worn glass with abrasion scratches from cleaning, corroded glass or coatings due to seal failure in IGUs or use of improperly processed ionomer interlayers.

Haze in transmission is the scattering of light by a specimen responsible for the reduction in contrast of objects viewed through it. It is the percentage of transmitted light that is scattered so that its direction deviates more than a specified angle from the direction of the incident beam (ASTM D1003).

The visual effect of haze is a loss of contrast produced by a veiling luminance. It will be most noticeable when the sun or a strong light source is shining on the glass surface. Haze will also create halos around aircraft lights at night.

Good cleaning of both surfaces will remove dirt and smoke, but replacement is the only cure for most other causes.

Crystalline structures will grow in ionomer interlayers when they are cooled too slowly. Thick multilayer laminates have a high thermal mass, and they are difficult to cool even in high-performance autoclaves. Therefore, it can be important to monitor their haze levels.

Laboratory haze measurement instruments, like BYK haze-gard I, cannot be used for in situ measurements. This apparatus is designed to measure thin materials and its readings will be affected by specimen thickness. Therefore, absolute measurements of thick laminates or IGUs are not possible.

Paragraph 5.3 (Task, 2017) mentions a maximum value range for haze of 0.7% to 2%.

The author is currently studying new methods to measure haze in situ and in manufacturing environments to obtain absolute values that are independent of the glass assembly thickness. Once this technical challenge is resolved, it will be possible to quantify known specimens and determine maximum values for each lighting condition.

Acknowledgements

We would like to thank Adrian Betanzos and his employer for their continuous support. They were instrumental in hosting the first meeting of the anisotropy task group and are now greatly involved in finding how to measure haze in architectural glass.

References

AS 2021:2015 - Acoustics - Aircraft Noise Intrusion - Building Siting and Construction. (2015) Committee EV-011, Australian Standards. https://ablis.business.gov.au/service/ag/australian-standard-as-2021-2015-acoustics-aircraft-noise-intrusion-building-siting-and-construction/31221

ASTM C1901-21, Standard Test Method for Measuring Optical Retardation in Flat Architectural Glass (2021). ASTM International, West Conshohocken, PA. http://www.astm.org

ASTM C1036-21 Standard Specification for Flat Glass. (2021). ASTM International, West Conshohocken, PA. http://www.astm.org

ASTM D1003-21 Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics (2021). ASTM International, West Conshohocken, PA. http://www.astm.org

ASTM E2461-22 Standard Practice for Determining the Thickness of Glass in Airport Traffic Control Tower Cabs (2022). ASTM International, West Conshohocken, PA. http://www.astm.org

Département Bâtiments: Les tours de contrôle, Fascicule 1-5 (2007), Services techniques de l’aviation civile, France

EN 572-2 Glass in Building - Basic Soda Lime Silicate Glass Products, Part 2 Float Glass (2012)

Semmelink, A: Study of noise in air route traffic control center, flight service station air traffic control tower and remote facilities, https://www.tc.faa.gov/its/worldpac/techrpt/rd72-47.pdf (1971)

Task, H.L.: FAA Air Traffic Control Tower Cab Glass Evaluation, Specification and Assessment with Respect to Optical-Visual Characteristics (2007), https://www.researchgate.net/publication/277741284_FAA_Air_Traffic_Control_Tower_Cab_Glass_Evaluation_Specification_and_Assessment_with_Respect_to_Optical-Visual_Characteristics

United Nations: Regulation No. 43 Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles (2017) - https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2017/R043r4e.pdf

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