# An analysis of the (BRE) average daylight factor and limiting depth guidelines as design criteria

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ABSTRACT

Following the study by V H C Crisp and P J Littlefair (CIBS, 1984)[1] on Average Daylight Factor Prediction, the arguments for the use of average daylight factor as a design criterion are reviewed in light of new experimental assessments. Part of the experiment carried out in 1984 with a physical scaled model under artificial sky, is repeated using Radiance.
It is shown that ADF is very sensitive to light distribution, hence the necessity to measure it with a tighter sensor grid spacing, than the one used previously, in order to avoid area weighted ADF and to increase accuracy.
It is shown that the new readings taken using Radiance and a tighter measurement grid, which starts right from the window-wall, can differ from the area weighted ADF by +30% to +5% as the window head increases in height. Conversely the modified Lynes (BRE) ADF formula assesses with greater precision the ADF for lower window heads 10% difference, up to 20% difference for higher ones, if compared with the new sets of Radiance readings for the proposed test rooms.
It should be also pinpointed to the fact that the test rooms modelled are based on 1954 typical post war classroom geometry, with 'ideal' window shape, running from wall to wall and cill to ceiling, and without any obstructions, while the ADF is currently used to assess dwellings in urban scenarios.
It is also suggested that the position and shape of the window influences the distribution of light over the working plane and therefore the reading of the ADF, by ±20% for the cases tested.
This difference cannot be taken into account either within the BRE ADF formula or within the limiting depth criterion.
Hence an eventual higher ADF does not necessarily equate to a better uniformity of light over the working plane and therefore does not ensure any energy savings for example, amongst other benefits that could be achieved by a correct understanding of its use.

## 1. INTRODUCTION

Two sets of experiments will be presented in this paper: the first one is concerned with the repetition of the test carried out by Crisp ad Littlefair for average daylight prediction; the second one concerns the sequencing process for daylight design included in BS 8206 part-2, which consists in applying a limiting depth criterion prior to average daylight factor formulae in order to ensure acceptable daylight distribution over the working plane of a single side lit room.

### *1.1 Background*

In 1984, V H Crisp and P J Littlefair tried to establish the accuracy of the predictions made by the available average daylight factor formulas, Longmore[2] and Lynes[3], through the comparison with experimental data. The experimental data was to be collected with the aid of a scale model and the use of an artificial sky.
The models used for the experiment were the same used in a previous study meant to understand the interreflection of daylight in rooms[4]. At that time, during preliminary studies in the model, a series of check measurements had been taken out doors, under densely overcast sky. The percentage deviation of corresponding measurements made with the artificial sky was less than ± 4% for each ceiling height and showed no significant variation with ceiling height or position in the room. The results obtained would have served the purpose of modifying Lynes formula in order to adjust its predictions to a given reference plane.
The study concludes by saying that the modified Lynes expression (BRE formula) and the Longmore expression, account for the measurements for the particular model rooms studied, with similar success. A spread of some ±10% about the 'ideal' line of perfect correlation can be regarded as adequate for initial design purposes. Two points are then emphasised:
1- Only a limited range of variables relevant to the calculation of average DF have been explored.
2- The necessity for further assessments are undertaken,

comprehending subjective assessment studies, to firmly establish suitable criterion values for average daylight factor as a design parameter.

*1.2 Description of experimental data modeling*

The experimental data were obtained using the classroom model described in the National Building studies research paper No. 24. [5]

Fig. 1 shows a plan and a section of the classroom and the disposition of the photocells from which an area-weighted average has been calculated. (Fig.2)

The model represents a classroom 26 ft 8 in. by 23 ft 4 in. (8.17 m x 7.13 m) and has a window extending from wall to wall and from a sill at 2 ft 8 in. (0.85 m) to the ceiling. The ceiling and the walls of the model could easily be adjusted; the former in height, and the latter substituted to test different reflectances.

The experiments have been carried out painting the interior walls with matt greys. The first set of reflection factors corresponding to Table 1. For the second experiment the model walls had reflection factors corresponding to Table 2.

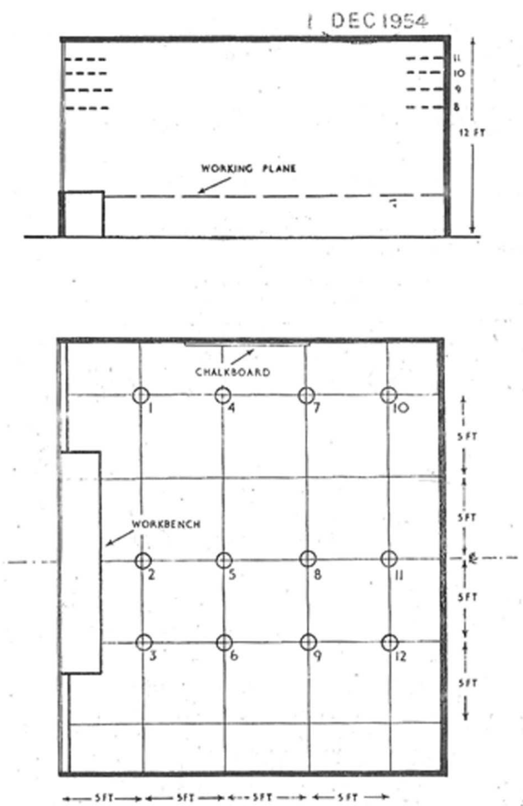



Fig.1: Plan and section of the classroom showing position of the photocells. Distanced 5ft (1.52 m) from the window-wall and between one another.

Table1: Reflection factors used in the model classroom “Standard Condition” classroom

| Surface | Proposed reflection factor (%) | Reflection factor used in model classroom (%) |
|---|---|---|
| Ceiling | 70 | 69,9 |
| Upper wall | 50 | 47,0 |
| Lower wall | 30 | 34,0 |
| Floor (polished wood) | 35 | 27,7 |
| Pin-up board | 25 | 22,1 |
| Chalk board | 15 | 14,8 |

Table2: Reflection factors of walls used in the model classroom.

| Surface/wall description | Reflection factor (%) |
|---|---|
| Ceiling | 69,9 |
| Floor (polished wood) | 14,8 |
| White | 82,0 |
| Light-grey | 67,9 |
| Mid-grey | 42,6 |
| Dark-grey | 26,7 |
| Black | 1,0 |

*1.3 Software*

Two different softwares have been used to model the same room described above. Ecotect[6] has been used to construct the model’s physics and to visualize the results; Radiance[7] has been used to carry out the simulations. Softwares enabled the use of many sensors on the reference plane, without any physical restriction in number. Moreover Radiance simulation properties, back ray tracing for example, account for the interreflection inside the room similarly to the sensors inside the scale model.

*1.4 Average Daylight Factor formulae*

Lynes:

$Df = tWQ/2A(1-R)$

Modified Lynes or BRE:

$Df = tWQ/A(1-R^2)$

Longmore:

$Df = tW\{C/A_{fw}+[CR_{fw}+5R_{cw}/A(1-R)]\}$

Where:

$A_{w}$: is the net glazed area of the window in $m^2$

Df: is the average daylight factor;

A: is the total area of the ceiling, floor and walls, including windows, in $m^2$;

R: is the area-weighted average reflectance of the interior surfaces (A);

t: is the diffuse light transmittance of the glazing including the effects of dirt;

Q: is the angle subtended by the visible sky (degrees) it is measured in a vertical plane Normal;

C: is a function of the daylight flux incident on the window pane from above the horizontal and varies with the sky luminance distribution and the external obstruction angle;

$A_{fw:}$ is the area of floor and lower parts of the walls below the mid height of the window (not including the window wall);

$R_{fw:}$ is the average reflectance of the $A_{fw}$ expressed as a decimal;

$R_{cw:}$ is the average reflectance of the ceiling and upper walls above the mid height of the window (not including the window wall) expressed as a decimal;

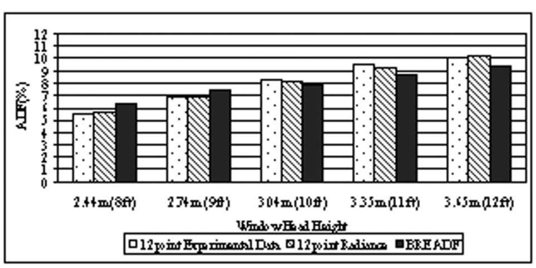
## 2. RESULTS

### *2.1 Comparison of the previous experimental data with Radiance simulation*

Results were obtained with two model configurations. In the first the walls had fixed reflectances ('Standard Condition'), but included a chalkboard and pin-up board, which due to the lack of information about their dimensions have not been included in the Radiance simulation; the difference attributed to the boards is not relevant to our purposes.

The main variable of the first model has been the height of the ceiling/window (8'/2,44 m – 12'/3,65 m).

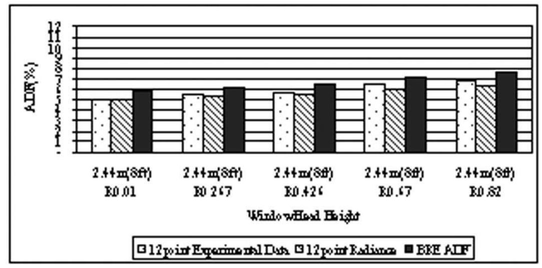
The second study was mainly concerned with the effect of different wall reflectance and for these measurements all the walls were of uniform reflectance and were changed at once, the ceiling and the floor kept at the same reflectance as the 'Standard Condition' model.



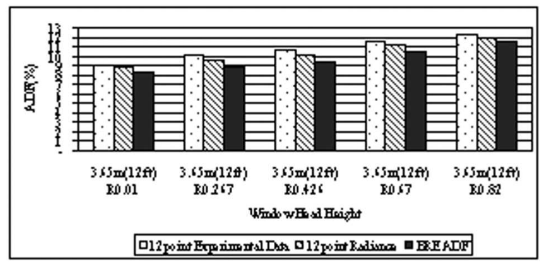

Graph1: Standard Condition classroom

Graph1 shows that Radiance compares well ±2% with the Experimental data for the Standards Condition model. The BRE ADF formula shows a spread of some ±10% about the 'ideal' line of perfect correlation with the experimental values, as reported by Crisp and Littlefair.

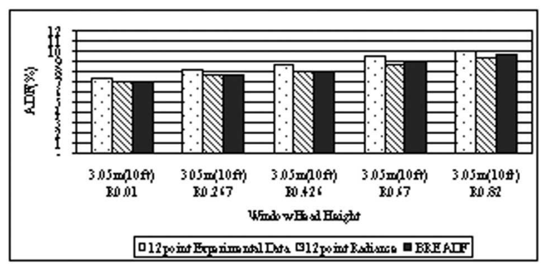
The BRE ADF seems to overestimate for lower window head heights and underestimate for higher ones.




Graph2: Uniform Wall Reflectance classroom for 2.44 m (8 ft) window head.




Graph3: Uniform Wall Reflectance classroom for 3.05 m (10 ft) window head.



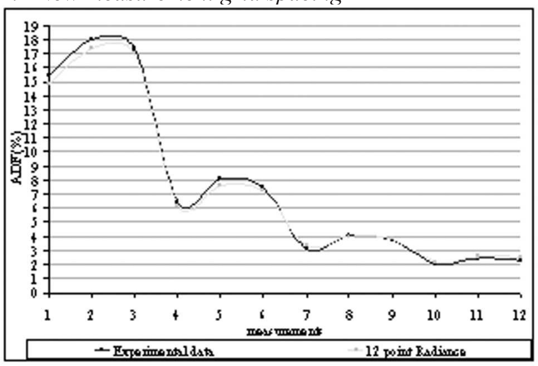

Graph4: Uniform Wall Reflectance classroom for 3.65 m (12 ft) window head.

Graphs 2-3-4 show the correlation between Radiance and the 2nd model tested, with uniform walls reflectance. Radiance\Experimental = 0.96 ±3%, which proves a very good adherence of the computer simulated scenario with the physical scaled model.

Throughout, the BRE ADF shows a spread of ±10% from an ideal correlation with the experimental data. In the instance of this second experiment, there is a very small divergence due to the different reflectance values used for the walls, but as for the previous model, the formula tends to overestimate values for a lower window head and underestimate for higher ones.

The BRE ADF seems to predict with greater accuracy values for a room with a window head of 10 ft (3.05 m).

*2.2 New measurement grid spacing*




Graph5: 12 Point measurements in rows parallel to the window-wall for Standard Condition classroom

As shown in Graph5 the highest values are to be read off the part of the plane which is closer to the window. Experimental data grid starts 1.52 m (5 ft) from the window. The requirement for new grid spacing is based on the necessity to eliminate the area weighted average (Fig.2), by dividing the space into equal portions. (Fig.3) Moreover, it is suggested that the division of the reference plane into appropriately small squares, in proportion to the dimensions of the subject room, 20cm x 20cm or 10cm x 10cm for example, can provide information relevant to the distribution of light when checking for uniformity on the working plane.

Graph6 shows the increasing ADF values read off a tighter grid.

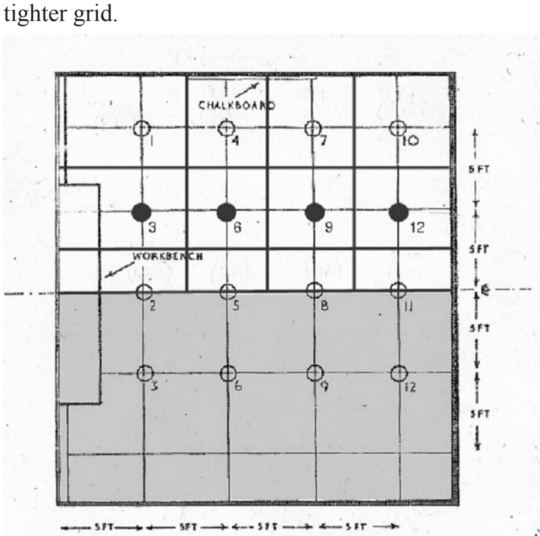



Fig.2: Plan and section of the classroom showing position of the photocells showing schema for area weighted average.
Cells are distant 5ft (1.52 m) from the window-wall and between one another.

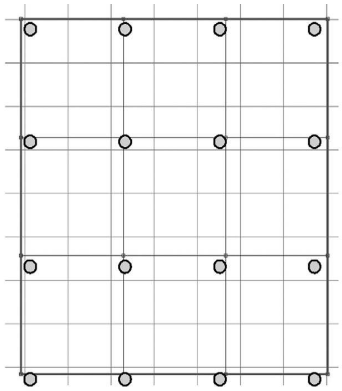
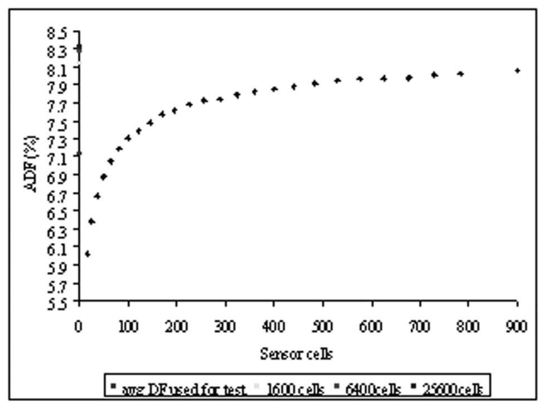


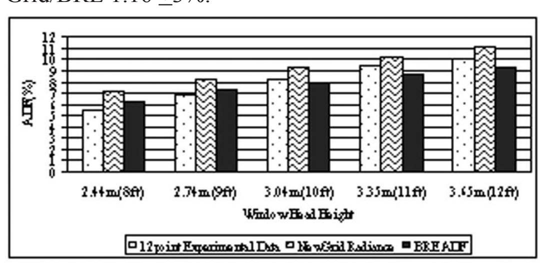
Fig.3: Even distribution of sensor cells over the grid across the room to avoid area weighted average.



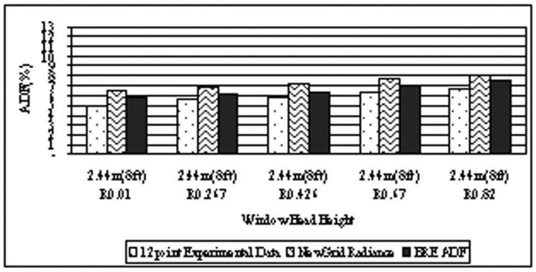

Graph6: ADF increases as the grid tightens. 25600cells = 10 cm x 10 cm squares.

*2.3 Comparison of the previous experimental data with NewGrid Radiance simulation (10 cm x 10 cm tight grid = 25600 sensor cells)*

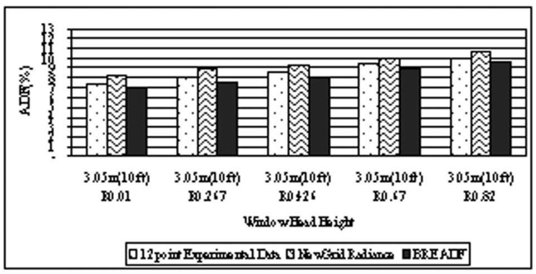
Graph7 shows the comparison between the New Radiance measurements the Experimental data and the BRE ADF formula values. It illustrates that for the Standard Condition classroom the new readings are always higher in values than both previous Experimental data NewGrid/Exp 1.16 ±9%, and BRE ADF values NewGrid/BRE 1.16 ±3%.



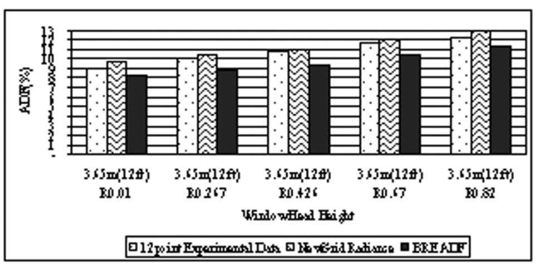

Graph7: Standard Condition classroom New Grid Radiance measurements




Graph8: Uniform Wall reflectance classroom New Grid Radiance measurements for 2.44 m (8 ft) window head.




Graph9: Uniform Wall reflectance classroom New Grid Radiance measurements for 3.05 m (10 ft) window head.




Graph10: Uniform Wall reflectance classroom New Grid Radiance measurements for 3.65 m (12 ft) window head.

Graph 8-9-10 show the comparison between the New Grid Radiance measurements the Experimental data and the BRE DF values.

It is clear from the graphs that the New Grid values are always higher than both the Experimental and the BRE ADF results. There is actually little difference occurring for higher wall reflectance, whilst there is a clear growing difference between New Grid and BRE ADF as the window head increases in height.

For window head 2.44 m (8 ft) Graph8, NewGrid/BRE ADF 1.11 ±3%;

For window head 3.05 m (10 ft) Graph9, NewGrid/BRE ADF 1.14 ±2%;

For window head 3.65 m (12 ft) Graph10, NewGrid/BRE ADF 1.17 ±2%;

This illustrates a constant increasing discrepancy of 3% as the window head grows in height.

## 3. LIMITING DEPTH EXPERIMENT

The sequencing process for daylight design included in BS 8206 part-2 consists in applying a limiting depth criterion prior to average daylight factor formulae in order to ensure acceptable daylight distribution over the working plane of a single side lit room.

In order to gather a little more insight into the effective meaning of designing for minimum average daylight factors and in light of the new grid spacing measurements, the following procedure was adopted.

The idea is to use the sequencing process that is suggested in the BRE guidelines and in the BS 8206, in order to consciously design a typical side lit room with an average daylight factor of 2%. The same room will be modelled with simulation softwares, Radiance and Ecotect, respectively to perform the daylight analysis and to visualize the results.

The aim is to double check the sequencing process accuracy at design stage and draw considerations on light distribution.

### *3.1 Settings*

Firstly room dimensions were created which fitted within the requirement of the limiting depth criterion and no-sky line. The criteria were designed to produce a sufficient uniformity of illuminance between the front and the back of the room. The limiting depth criterion is based on the ratio between the ADF in the front half of the room and the rear half not exceeding 3. As written in the BS 8206: "in a room with windows in one wall only, the following inequality should be satisfied."[8]

$L/W + L/H \leq 2/1-R_b$

Where:

- L: is the depth of the room from window to back wall;
- W: is the width of the room, measured parallel to the window;
- H: is the height of the window head above floor level;
- $R_b$: is the area-weighted average reflectance of the interior surfaces (walls, floor and ceiling) in the half of the room remote from the window.

The test room dimensions are:

L = 4 m W = 2,5 m H = 2.7 m $R_b$ = 0.5

The resulting inequality is: $3{,}08 \leq 4$

This means that the room length is well within the limiting depth. Given that the room is not very deep, there are no external obstructions and the window head is as high as possible, the whole reference plane has a direct view of the sky; there is no 'no-sky line.'

In order now to produce the adequate window size to

obtain an average daylight factor of 2%, we are going to reverse the BRE average daylight formula.
$A_w = Df\,A\,(1 - R^2) / T\,Q$
The room in our test will be privileged by an ideal situation of no obstruction.
Its Q angle will be 90 degrees, because no window reveals have been simulated.
Our window will be fitted with a double glazed window pane with T = 0.7
Maintenance factor = nil Resulting T = 0.7
The walls have a reflectance of R = 0.5 on average.
Respectively: ceiling R = 0.7; walls R = 0.5; floor R = 0.3
Applying the inverted average daylight formula:
$A_w = 2 \times 55.1 \times 0.75 / 0.7 \times 90 = 1.31\,m^2$
The shape and position of the window has to be decided. The hypotheses are that the back of the room will be the area with the lowest average daylight factor; hence the window head should be as high as possible. The position of the window or its shape should not really affect the total average daylight factor as long as its area size is kept the same. If one respects the limiting depth criteria and the average daylight factor formula, one would not really have to check with point to point methods since the minimum average daylight factor will be as high as circumstances permit.[9]

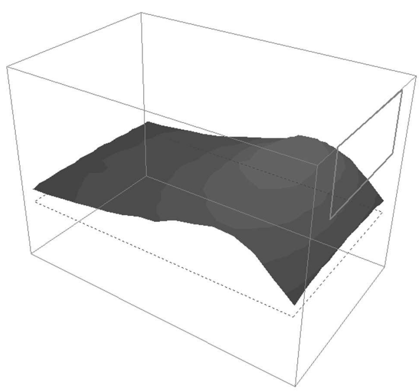


Fig.4 Horizontal window

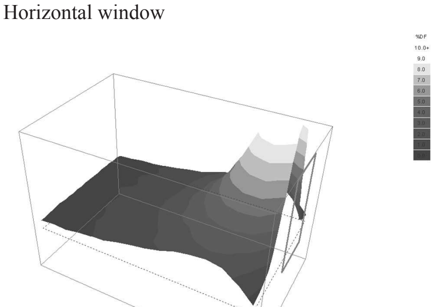


Fig.5 Vertical window


Fig.6 Horizontal w.

Fig.7 Vertical w.

Horizontal window = ADF 2.1%
Vertical window = ADF 2.7%
BRE = ADF 2.0%

## 4. CONCLUSION

The tests with the tighter measurement grid spacing show that the BRE Average Daylight Factor formula underestimates the actual value by between 10% to 20% for the model rooms tested (Graph7-10). The consistent underestimation is due to the fact that the BRE ADF formula has been empirically corrected to fit the experimental data under the artificial sky and the small number of sensors used to average the daylight factor readings, could not take into account all the high values falling on the 'reference plane' next to the window-wall. This proves that the criteria given as guidance are all relative and only further tests, changing room depth and width could actually increase the accuracy of the formula and generalize concretely its predicting ability.
When used as a design aid, one has to be conscious that ultimately the shape of the window dictates the distribution of light entering the room, and thus it can affect the actual average daylight factor value; in the example given in Fig.4-7 by ± 20%. Hence a higher ADF does not always equate to a more uniform and better lit environment and certainly does not ensure any energy savings per se. Further tests should be carried out in order to confirm the uniformity ratio 3:1 between the BRE ADF in the front half and the rear half or the room, as it proved to be very sensitive to window shape and light distribution pattern, which is not accounted for either in the BRE ADF or in the limiting depth criterion formulae. Ultimately, even though the sequencing suggested in the guidelines and codes of practice could roughly inform the designer on the daylight entering a room, it still does not provide

any concrete reference on which to assess the validity, appropriateness and usefulness of the proposed design. It is clear that the Average Daylight Factor approach finds its best application if used at early design stage, by no means should it be intended as a stand alone guarantee for a correct illuminance of a day lit space, especially if one designs for eventual task lighting.

Ultimately it seems fairly evident that the suggested percentages of average daylight factor did not intend to set a precise design criterion yet, as they are based upon a very small number of 'ideally' unobstructed tested scenarios. It is unfortunate though that architects, planners and specialists seem to take those values as a definite criterion and based on a ±0.01% discrepancy inform planning application 'passes or failures' and appeals.

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