As the COVID-19 crisis prevented us from getting data for this report, all photos and measurements are taken from group B02 - Shanna Nabavi and May Salama. When possible, we took images they did not use themselves to make this report different. Sometimes, the pictures lacked proper documentation and thus, we used their report to work things out backwards to the best of our ability.

Multimode fibre

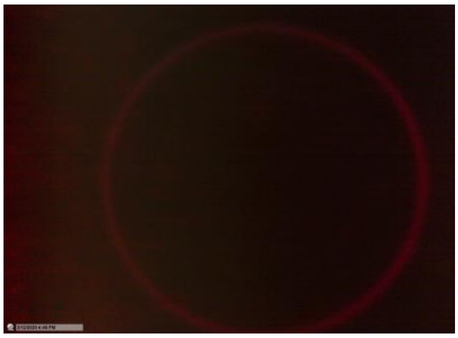
5. Summary of tasks of the experimental work

4.2. Evaluation of the numerical aperture with skewed rays (40 min)

Show images obtained at different skew ray configurations. **(2 images)** Measure the acceptance angle of the fibre and compute its numerical aperture. Provide an error estimation of the measurement. Compare the measured value with the datasheet of the fibre.

Picture1– Skewed rays (~20°)

Picture 2 – Skewed rays (~30°)



Acceptance angle by direct measurement (deg): 30°
Error evaluation: ± 5°

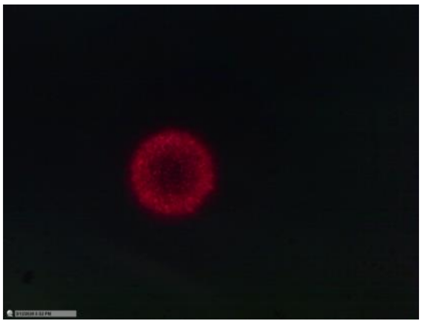
From datasheet (page 5 of TP description): NA = 0.22
Datasheet value (half acceptance angle θ=arcsin (NA)): arcsin(0.22) = 12.7°

Discussion (compare and interpret):
The acceptance angle has been measured to be 30°, from the datasheet we compute it to be 25.4°, which fits the error estimation made by group B02.

From the 30° angle we measured, the half angle is 15° and NA is around 0.26. This is an acceptable error. Some of it may be due to light propagating through the cladding or even the jacket of the fiber but those are handmade measurements and human error is probably the real cause of the difference in values.

4.3 Measurement of the numerical aperture (40 min)

Show sample images for light spot on the camera (**2 images**). Provide a table with the spot diameter as a function of distance (min. 5 points). Calculate the NA of the fibre. Provide an error estimation. Compare the value with the value obtain with skewed rays and with the datasheet of the fibre.

Picture 1–Spot size at position 3	Picture 2–Spot size at position 7
	

Measurement number	1	2	3	4	5	6	7
Distance mm	0	0.5	0.83	1.51	2.11	2.68	3.66
Spot diameter pxl	110	120	160	200	230	285	325
Spot diameter in mm (1px = 2.835um)	0.31	0.34	0.45	0.57	0.65	0.81	0.92
Angle (deg) (half angle) = arctan(spot radius/distance)		18.77	15.16	10.69	8.76	8.59	7.16
NA = n sin(half angle) For air n = 1		0.32	0.26	0.19	0.15	0.15	0.12

Average numerical aperture of the fibre NA= 0.20

Standard deviation of NA ΔNA = sqrt(sum((value-average)2)/6) = 0.07

Comparison with value obtained with skewed rays and datasheet. Interpret your result (a few sentences)

Compared to skewed rays, our value is closer to the one found in the datasheet as light travels through the center of the fiber, with less dispersion.

As we decrease the angle/increase the distance between the source and the fiber, the spot size increases as light is more dispersed when it enters the fiber and thus at the exit as well. In multimode fibers the light has a lot of space to bounce off the walls etc. in contrast to monomode fibers in which the path is more straight forward.

The darkened center of the spot is due to destructive interferences and laser speckles.

4.4. Injection for different sources (20 min)

Show sample images for light spots on the camera for each source **(3 Images).** What is special for each source? Please comment! (i.e. the granular structure of the laser, overall light level, size of the spot)

Picture 1 – Halogen	Picture 2 – LED	Picture 3 – Laser
		

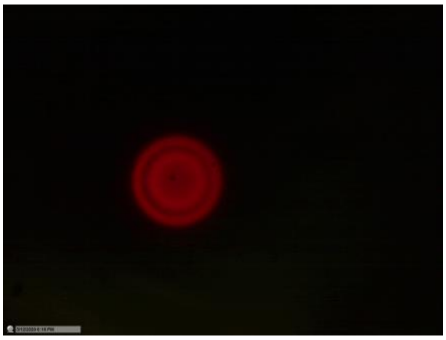
Comments:
The larger the spectral bandwidth, the more homogenous the spot is. This is because dispersion is a function of the wavelength and therefore, some wavelengths "compensate" others at the exit of the fiber. This also makes the spot brighter – more light reaches the detector.

In the full-scale image, we can observe laser speckles. These are not compensated by other wavelengths as the laser is a coherent source with a well-defined wavelength.

We find it strange that the spot size of the halogen source is so small. We expected it closer to the LED's size. In both of these sources we can observe some outer ring (halo?) which we think comes from light propagating through the cladding and deviating slightly differently at the exit because of the different refraction index.

4.5 Measurement of relative injection efficiency (20 min)

Show the **two images**. Measure the distance between the lens cap and the entrance of the fibre for both situations and calculate the NA. Compare the total intensity for the two injection conditions by integrating the intensities with Matlab. Give the integral intensities for all images. Give the ratio for the background corrected and non-corrected value. Calculate P_1/P_2 as given above. (No error calculations needed)

Picture 1 – LED position 1	Picture 1 – LED position 2
	

Position	1	2
Distance lens cap fibre entrance	23mm	52mm
Numerical aperture NA Calculated using eq. (11) from TP description – lens diameter = 9mm	0.20	0.09
Total intensity no background correction	20 284 356	13 631 025
Total intensity with background correction	9 850 409	3 197 078

Ratio of injected power $P_1/P_2 = 3.08$

Ratio of NA $NA_{12}/NA_{22} = 4.94$

Compare power and NA ratio and interpret your result:
As per the development of eq. (12) from TP description the ratios should be identical.

This is not our case, some of this is due to measurement errors, be it in the adjustment of the setup or calibration of matlab for the power computations. Both of these parameters can vary the result substantially with a slight variation in the numbers.

Personal feedback:

Was the amount of work adequate? Yes

What is difficult to understand? No

What did you like about it? The Wikipedia page is very interesting, and it was good to have done the TP that came after to notice some more subtle things in this one.

How can we do better? Giving us the data, or better communication about this TP would have been appreciated but we understand.