LIGO TECHNICAL BOARD

Discussion of Glass Shedding from LIGO Beam Tube Baffles

W. E. Althouse

January 16, 1997

Particle Shedding from Baffles

Location	Type	Glaze T_1+T_2 .001 in		Time days	Size μm	Number	LIGO Rate count/hr
		Cone	Teeth				
#18 (MIT shake)	Serrated	18	31	3	> 100	500	160
#19 (MIT shake)	Serrated	14	17	2	> 100	18	9
CIT mockup #1	Serrated	17	21	16	> 100	360	22
WA BT #1	Serrated			21	> 500	500	70
WA BT #2	Serrated			21	> 500	60	9
WA BT #3	Serrated			16	> 500	40	7
WA BT #4	Serrated			16	> 500	20	4
WA BT #5	Non-serrated			20	> 500	2-5	.2-.6
CIT mockup #2	Non-serrated	4-8		4	> 100	21	5
						Maximum allowable:	1

Assumptions

- All serrated baffles on hand are suspect or NG.
- All serrated baffles already installed must be removed.
- Non-serrated baffles (all on this arm are already installed) may be ok or may need to be removed (further investigation needed).
- CBI installation schedule must be maintained.
- CBI will install at the planned 10 sections/week (5 sections/week on each module, or 20 sections on each module in 4 weeks).
- We can go at least 20 sections (400m) deep into the tube to install baffles, at least in the low-density regions.

Contingency Actions

- Stop installation of baffles (effective ~1/7)
- Oxidize 30 unglazed baffle substrates from West Coast Porcelain in-process stock (ready)
- Fabricated and oxidize 50 baffles using #2B (bright-annealed) cold-rolled SS (should be ready around 2/1)
- Conduction lab experiments on samples of glazed material (on-going)
- Decide how to handle Capitol and West Coast Porcelain contracts

Alternative Materials Optical Performance

Material	Oxide	BRDF @1μm, 55° $1000 \cdot sr^{-1}$	R	$R^2 \cdot BRDF_{wall}$ $1000 \cdot sr^{-1}$	Sum $1000 \cdot sr^{-1}$	Effect on Strain Sensitivity
Glass	–	1-3	< .13	< 1	1-3	1
#2B	none	1-3	.5-.55	15-18	16-21	3
#2B	450°C, 4hr	1-4	.4-.45	10-12	11-16	2.5
#2B	450°C, 8hr	4	.35-.45	7-12	11-16	2.5
#2B	450°C, 40hr	13	.22-.4	3-10	16-23	3
Grit-blasted SS	glass firing process	60	diffuse	–	60	6
BT wall mat'l		30	diffuse	–	30	4

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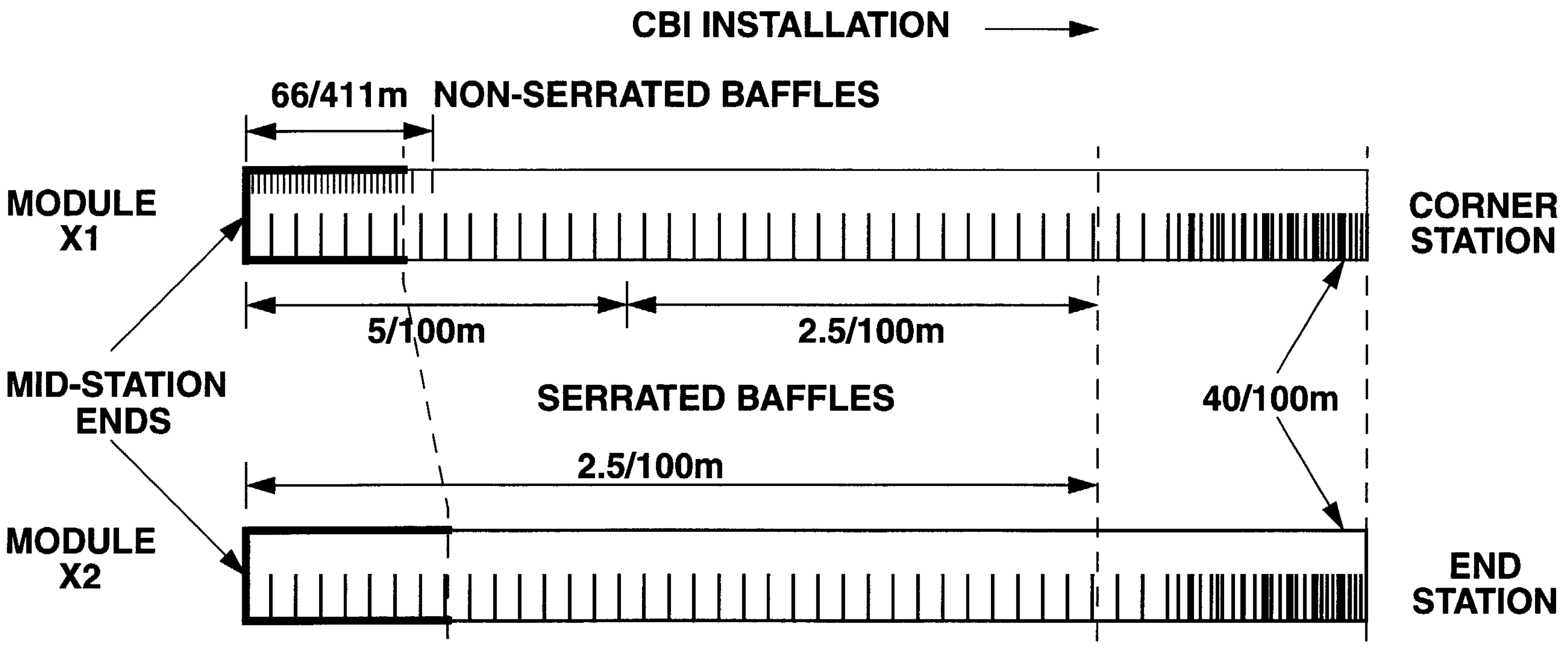
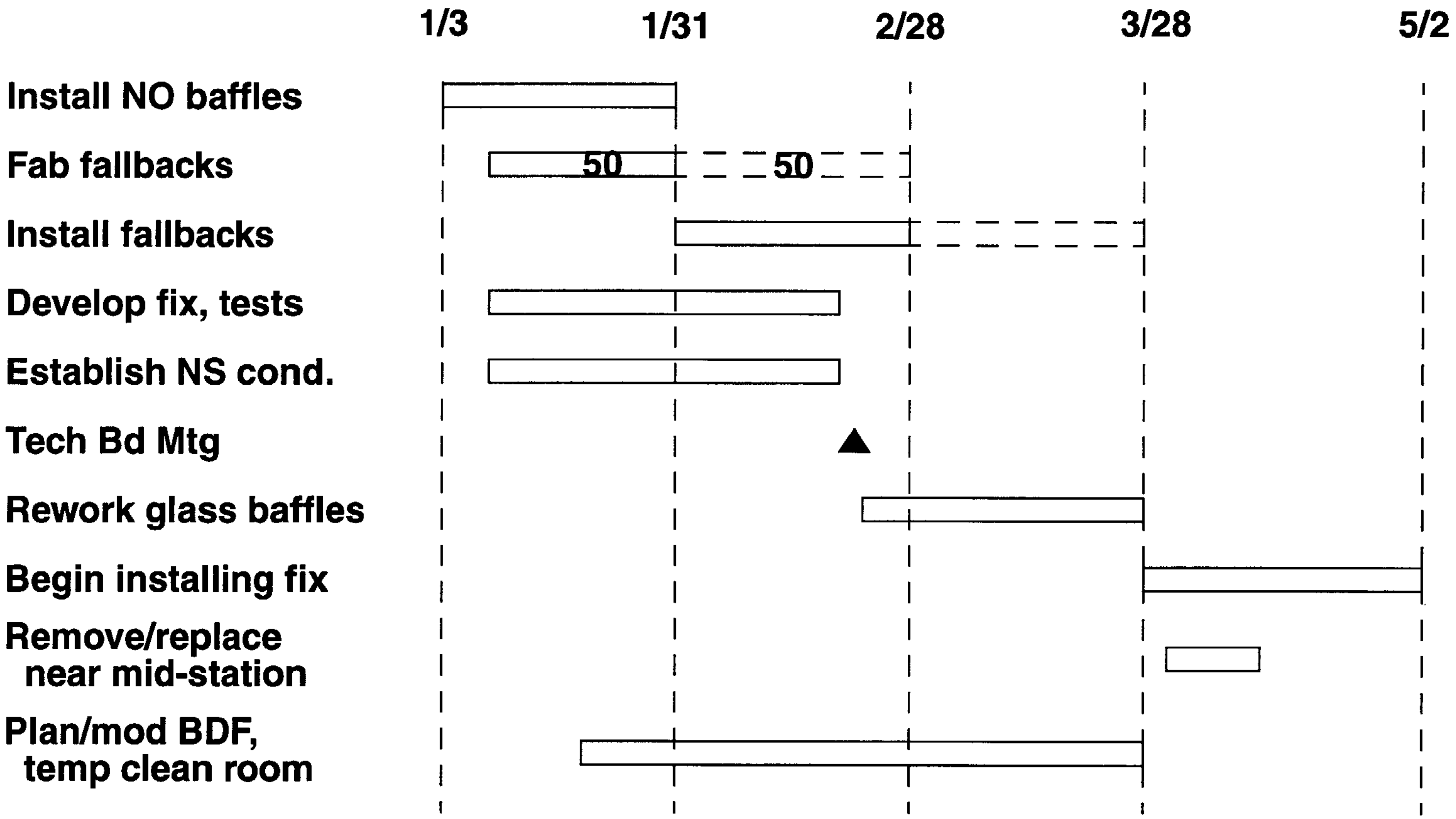
Schedule Considerations



STATUS AS OF:	1/3/97		3/28/97		5/2/97	
	X1	X2	X1	X2	X1	X2
# 20m SECTIONS	14	17	75	75	100	100
# N.S. BAFFLES	64	-	66	-	66	-
# SER. BAFFLES	14	9	55	40	123	107

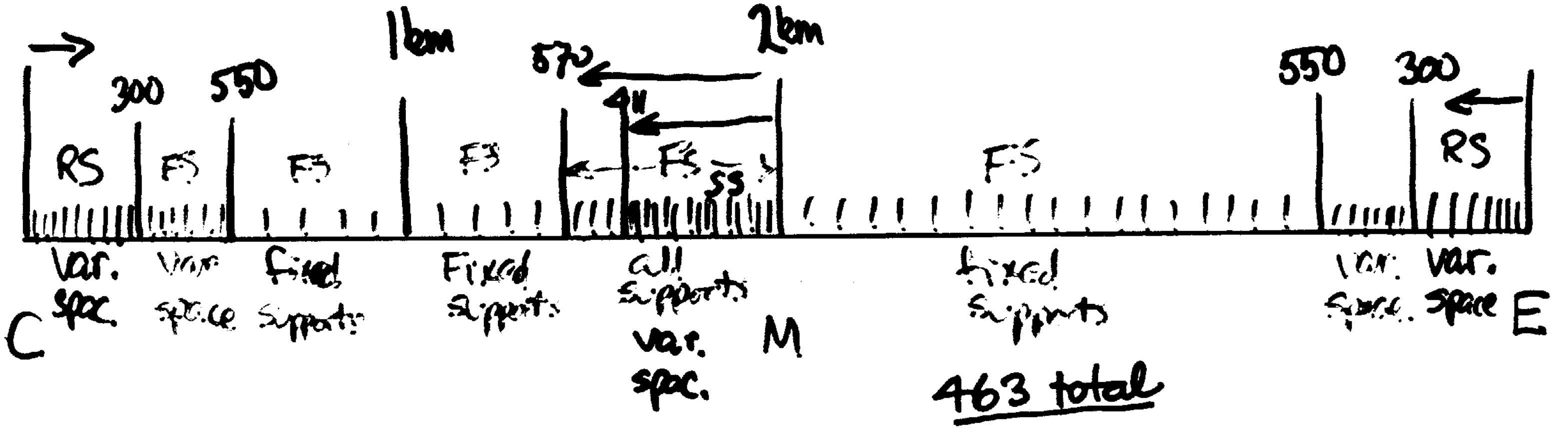
A Recovery Plan



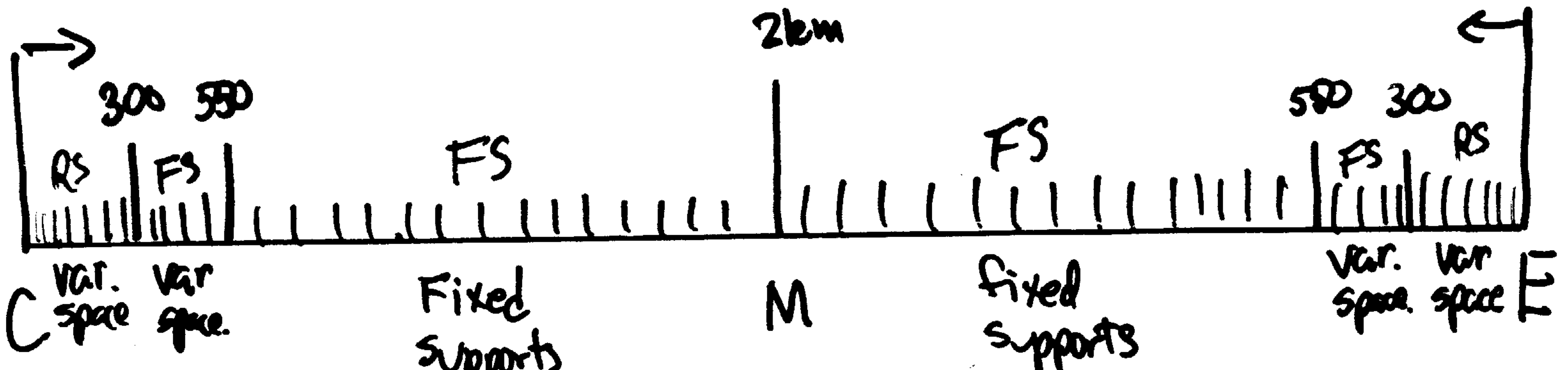
BACKUP

MATERIAL

WA



LA



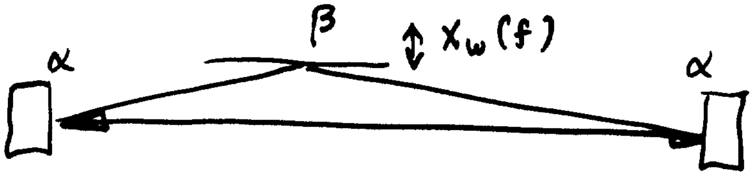
362 total

RS ≡ Reduced serrations [greater avg. height ⇒ reduced # at densest spacing]

FS ≡ full serration - original baffles

SS ≡ shallow serration - improves 4km IFO scatter from diffraction from 2km baffles

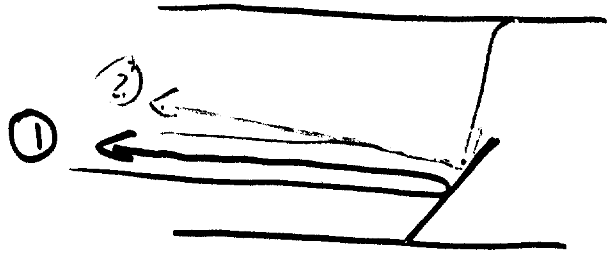
A



Scatter & Recombination

$$h^2 \sim x_w^2 \, \beta \alpha^2$$

B



① power ~ $BRDF_{Baffle}$

② Power ~ $R^2_{Baffle} \, BRDF_{Tube\ wall}$

C

	BRDF	R^2 $BRDF_{Tube}$	$\sqrt{\Sigma}$
Black glaze	$2\text{-}5 \times 10^{-3}$	$(.1)^2 (.06)$	.04 – .07
oxidized polish 304SS	$3\text{-}5 \times 10^{-3}$	$(.45)^2 (.06)$	.11

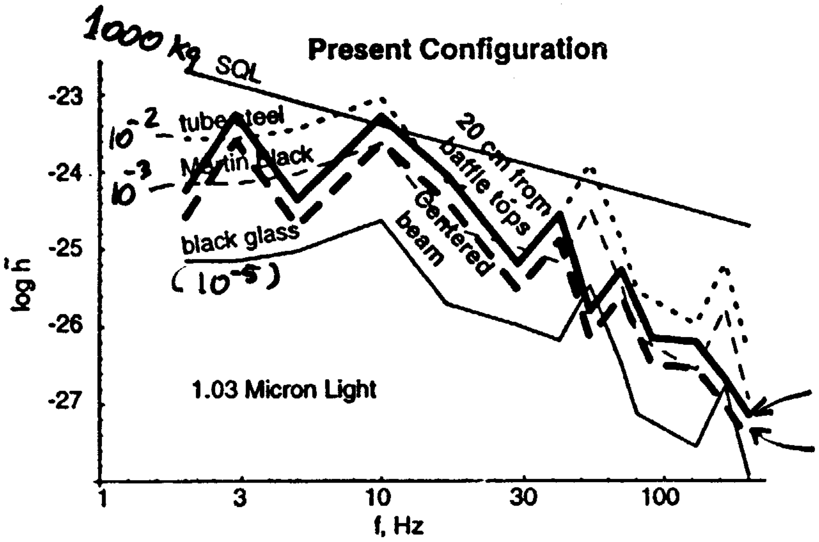
Considerations for baffle performance

(ref Note from Throne)
15-1-97

- Diffraction affected by serrations
- Backscatter affected by glaze
- Presently, Diffraction ~ Backscatter
- Backscatter degradation ~ $\sqrt{\frac{BRDF_{new}}{BRDF_{old}}}$
- Diffraction contribution comes from all serrated baffles (not just ones in center of tube)
  - for centered mirror (not presently the case) degradation: $\underset{\sim}{17x} \rightarrow \underset{\sim}{350x}$!
  - for off centered (extreme) mirror (not presently the ca
    degradation ~10x

Bottom line:

- Keep serrations - impact ≳10x (severe)
- Degradation due to backscatter less severe ≲5x



$\tilde{h} \sim \gamma_{wall} \cdot \alpha_{mirror} \cdot \sqrt{\beta_{baffle}}$

diffraction [serrations, not affected by glaze]

backscatter [glaze, not affected by serrations]

Present estimates for glazed baffles

FIG. 1. Diffraction noise (thick curves), compared to backscatter noise (thin curves), at Hanford for the present baffle configuration. The thick solid curve is for the main-beam axis 20cm away from the nearest baffle tops; the thick dashed curve is for the main-beam axis at the center of the beam tube.

II. DEPENDENCE OF NOISE ON BAFFLE MATERIAL

The backscatter noise is shown in the above figure for several baffle materials that were being discussed in spring 1995; these materials were assumed to have BRDF's

- $\beta \simeq 0.01$ to 0.02 for beam-tube steel.
- $\beta \simeq 10^{-3}$ for Martin black.
- $\beta \sim 10^{-5}$ for black glass.

Thin curves

The noise scales as

$$\tilde{h} \propto \sqrt{\beta}\,. \tag{1}$$

Our present baffles, as I recall, have $\beta = (\text{a few}) \times 10^{-3}$, i.e., a little worse than Martin black, when one includes both the actual backscatter off the baffles and reflection, tube-backscatter, reflection. — Thick curves

If we change baffle surfaces to something whose total BRDF (including actual backscatter, and reflection, tube backscatter, reflection) is a factor γ larger than the present BRDF, our noise will increase by a factor

$$\left(\frac{\tilde{h}}{\tilde{h}_o}\right)_{BS} = \sqrt{\gamma}\,. \tag{2}$$

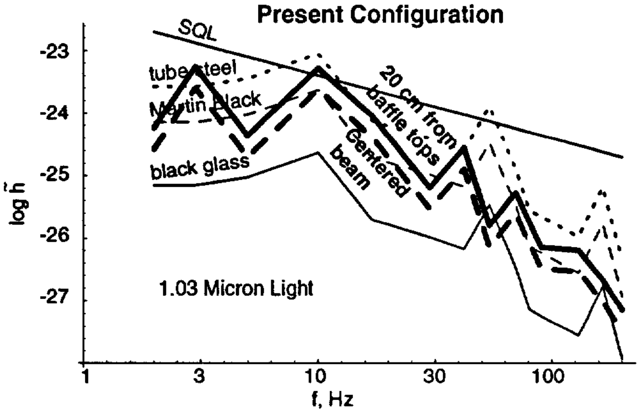
Relative figure of merit for backscatter degradation

Dependence of Scattered-Light Noise on Baffle Materials and Serrations

Kip S. Thorne
Caltech Relativity Theory Group (CaRT)
(15 January 1997)

I. NOISE FOR PRESENT BAFFLE CONFIGURATION

Our best noise estimates for the present baffle configuration are shown in the figure below. The assumptions going into these noise estimates are discussed in LIGO-T950102-00-E [Flanagan and Thorne, "Scattered-Light Noise for LIGO", 2 April 1995]. The noise shown below is identical to Fig. 9 of that reference, except that the diffraction noise has been increased by about a factor 2 as a result of taller baffles than assumed in that report, and extensive numerical computations that Flanagan and I carried out in the summer and autumn of 1995.



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Our present baffles, as I recall, have $\beta = (\text{a few}) \times 10^{-3}$, i.e., a little worse than Martin black, when one includes both the actual backscatter off the baffles and reflection, tube-backscatter, reflection.

If we change baffle surfaces to something whose total BRDF (including actual backscatter, and reflection, tube backscatter, reflection) is a factor γ larger than the present BRDF, our noise will increase by a factor

$$\left(\frac{\tilde{h}}{\tilde{h}_o}\right)_{BS} = \sqrt{\gamma}\,. \tag{2}$$

This worsening of noise would be about a factor 5.5 for $\gamma = 30$, and 1.7 for $\gamma = 3$.

If we use baffles with backscatter factor γ_1 in the tube ends, going downward a distance l_1 from the corner and end mirrors, and then switch to baffles with backscatter factor γ_2 in the central regions of the tube, then for the 4 km interferometers, the noise will increase by a factor [cf. Eq. (8) of the above reference]:

$$\left(\frac{\tilde{h}}{\tilde{h}_o}\right)_{BS} = \sqrt{\frac{\gamma_1 \ln(l_1/l_0) + \gamma_2 \ln(l_2/l_1) + \gamma_3 \ln(L/l_2)}{\ln(L/l_0)}} \tag{3}$$

Here $l_0 \simeq 12$m is the distance from the corner or end mirror to the first baffle, l_1 is the distance from the mirror to the location where the new baffle material begins, $l_2 = L - l_1$ is the distance from the mirror to the location where the baffle material changes again, and $L = 4$km is the tube length. For example, if the central 2 km uses baffles with $\gamma = 30$, and the two outer 1 km stretches use baffles with $\gamma = 1$ [so $l_0 = 12$m, $l_1 = 1$km, $l_2 = 3$km, $\gamma_1 = 1$, $\gamma_2 = 30$, the backscatter noise will be increased by a factor 2.5, which is significantly less than $\sqrt{30} = 5.5$ for baffles all with $\gamma = 30$. However, in this case the backscatter noise in the 2km interferometer would go up by nearly $\sqrt{30} = 5.5$.

III. DIFFRACTION NOISE

Contrary to what I had remembered, in the absence of serrations every baffle will contribute roughly equally to the diffraction noise, whether it is near the tube center or near a tube end. This is because the diffraction noise can be thought of as due to light from an extremely thin strip (thickness $\ll$ wavelength of light) along the baffle edge, which is uncovered then recovered as the baffle vibrates, and such a thin strip radiates roughly isotropically.

This means that we cannot keep our diffraction noise down by using serrations only near the tube center and switching to unserrated or gently scalloped baffles near the ends.

If all the presently serrated baffles were made unserrated, or were very gently scalloped, then the noise would increase by the following amounts:

When the beam is centered in the beam-tube cross section (the most dangerous case), then removing the serrations would increase the noise by a factor [cf. Eq. (9) of above reference]:

$$\left(\frac{\tilde{h}}{\tilde{h}_0}\right)_{\text{Diff, centered}} = \left(2\frac{8\pi(R-H)\Delta H}{\sqrt{2}\lambda L}\right)\left(\frac{2\pi(R-H)}{\sqrt{\lambda L/4}}\right)^{1/2} \simeq 35 \times 10 = 350\,. \tag{4}$$

Here $R = 60$cm is the tube radius, $H = 8.4$cm is the mean baffle height, $\Delta H = 0.8$cm is the mean depth of the serrations, λ is the wavelength of the light, and $L = 4$km is the tube length. The first factor 2 comes from the weighted sum over all baffles [the last term in Eq. (9) of the above reference]. The first term in Eq. (4), whose value is 35, is the factor we lose because the serration edges produce an averaging of the noise over a number of Fresnel zones; and the second term, whose value is 10, is the factor we lose because the serrations' randomness was enforcing incoherence around the baffle edge. In reality, irregularities in the mirrors may well enforce incoherence around the baffle edge without the aid of baffle randomness, so we may well not worsen the noise by this second factor 10; the net worsening may be only 35 rather than 350. Moreover, Eanna's and my numerical calculations suggest that we might not gain the full factor 35 from serration edge averaging; it might be anywhere between 17 and 35.

The bottom line is that removing the serrations will increase the amplitude of the diffraction noise for centered mirrors by a factor between 17 and 350.

When the beam is substantially off center, a distance Y from the mean baffle top, then removing the serrations increases the diffraction noise by [cf. Eqs. (10) and (11) and associated discussion in above reference]

$$\left(\frac{\tilde{h}}{\tilde{h}_0}\right)_{\text{Diff, Off-Cen}} = 2\frac{8\pi Y\Delta H}{\sqrt{2}\lambda L}\,. \tag{5}$$

This noise increase comes entirely from the baffle-edge averaging over Fresnel zones; for off centered beams the Fresnel zone pattern always, in effect, enforces incoherence: random serrations are not needed for that purpose.

If the beam is a distance $Y = 20$cm from the mean baffle tops, as in the above figure, then this increase in the amplitude of the diffraction noise is a factor 10.

I believe that we cannot afford to give up our baffle serrations; the increase in diffraction losses — a factor 17 to 350 for centered beams, a factor 10 for significantly off-centered beams — is unacceptably large.