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DEFINING AND TESTING THE SOUND INSULATION OF PARTIALLY OPEN WINDOWS

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ABSTRACT

Sound insulation with partially open windows has had growing attention in recent years. In Denmark, this is primarily caused by the Danish Environmental Protection Agency's guideline from 2007 "Noise from roads", which introduces noise limits with open windows (opening area of 0.35 m^2) for situations with a high traffic noise level. This has naturally led to innovation, and new complex window types have been invented and tested. For complex solutions as the Supply Air Window which is a type of air lock, a good correlation between laboratory and field test have been found. Less is known about applicability of measurement methods for simple open windows, which are investigated in a research project with the title "Optimized measurement method for sound reduction of partially open windows (METÅV)".

The primary focus of the project is to explore alternative laboratory methods to the traditional diffuse field method by studying reference cases from field measurements and taking into consideration different sound source positions and window geometry. This paper describes the background of the project and the results so far.

Keywords: *sound insulation, partially open windows, standardization.*

1. INTRODUCTION

Typically, regulations for sound insulation for facades and windows are concerned only with closed windows, and accordingly the standards for quantifying the sound insulation are typically designed for closed windows. One might however need to quantify the sound insulation for partially open windows as well. This question is especially important in Denmark, where regulation since 2007 has lined up guidelines for partially open windows, as well if the outdoor noise level exceeds a certain threshold [1]-[3].

In these guides a requirement is set for special situations, where the outdoor noise level from e.g. road traffic or railroads is high, the indoor noise level in e.g. apartments and offices must be below a certain level with open windows, when the opening area is 0.35 m^2 for each openable window.

The method to verify compliance with limits consists of a combination of calculation of the façade noise level together with documentation of the sound reduction for the chosen window solution.

The guidelines have naturally led to innovation in this area [4]-[11], and the quantification methods (ISO 16283-3 [12] and ISO 10140-2 [13]) have previously been tested for some of the more complex solutions [14], which can be described as a sort of airlock/channel, see Figure 1.

However, at the moment there is much focus on more simple solutions, and in parallel to the ongoing revision of ISO 16283-3 it has been chosen to study the applicability of existing standards for simple partially open windows in a small research project with the title "Optimized measurement method for sound reduction of partially open windows (METÅV)".

Supplementary in 2022, a case study was performed testing the applicability of ISO 16283-3 for a simple partially open window by comparing results with both traffic noise and loudspeaker noise as noise sources together with a new method described as "moving loudspeaker" [15].

The concept of sound insulation of partially open windows is also of interest outside of Denmark, for example in the UK [16][17], but the level of interest is very different from country to country, as well as how the concept of sound insulation of partially open windows is handled.

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2. PARTIALLY OPEN WINDOWS

First, let us define some differences between the relevant window types typically used in Denmark.

2.1 Complex partially open windows

The most efficient window types in terms of sound insulation are the ones where the sound/air path is prolonged as a sort of airlock/channel. Two of the most popular solutions in Denmark can be seen below in Figure 1. Much innovation has been performed on these types [4]-[11]. However, for a number of reasons (e.g. ventilation, fresh air requirements, regulations etc.) simpler solutions are needed as well.

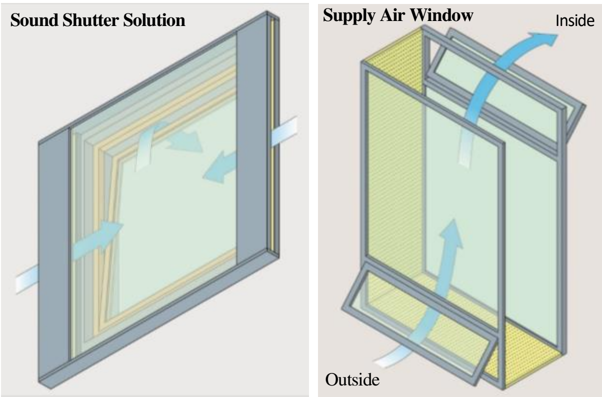

Figure 1. Drawings of complex partially open windows [8]. Left: The sound shutter solution. Right: The Supply Air Window.

2.2 Simple/regular partially open windows

Figure 2 shows examples of regular Danish windows each mounted in the laboratory according to ISO 10140-1 [13] and opened 0.35 m^2 fulfilling the Danish rule for opening area. These examples are the simplest Danish version of ordinary partially open windows.

2.3 Simple partially open windows utilizing geometry

For the simple open windows, it is sometimes possible to "squeeze out" a few more dB of sound insulation if the outdoor noise comes from a specific direction. For example, a side-hung outward opening window in a façade perpendicular to the traffic noise can shield the noise somewhat if the opening is away from the noise. Another example is with a window as shown in Figure 3, where this solution can offer extra shielding from noise sources placed close to the ground due to the extra added glass plate.

Figure 2. Photos of laboratory measurements of simple/regular partially open windows, all opened 0.35 m^2. Window types: top left: side-hung (SH), top right: top-hung (TH), bottom left: Dannebrog (DBR), bottom right: split side-hung (SSH). [5]

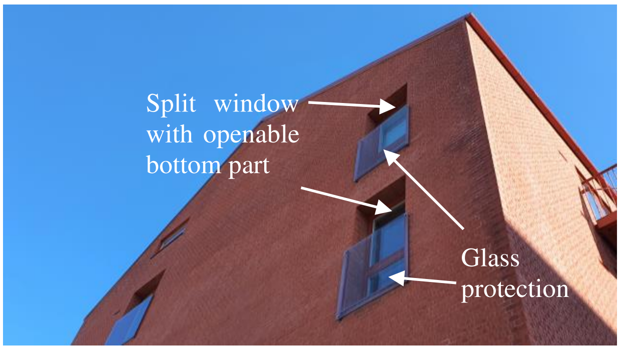

Figure 3. Photo of example of simple partially shielded window utilizing geometry. The window is a split window where the bottom part can be opened, and where a glass plate has been added over the bottom part. This solution can offer extra shielding from low-placed noise sources by opening the bottom part of the window.

3. "OPTIMIZED MEASUREMENT METHOD FOR SOUND REDUCTION OF PARTIALLY OPEN WINDOWS (METÅV)"

The focus of the small research project "Optimized measurement method for sound reduction of partially open windows (METÅV)" is the sound insulation of simple windows described in the previous sections, especially the simple partially open windows utilizing different geometry since it is the hypothesis that laboratory measurements according to ISO 10140 series of ordinary windows yield conservative values compared to field measurements due to the diffuse field conditions in the laboratory. In the diffuse sound field sound will 'hit' the open window from all directions, which is not necessarily the case in the real world. Not having a diffuse field of course introduces new questions; for example, where to position the microphones, how to position the noise source with regards to the window, and how to best represent the noise source, for example road traffic.

The METÅV project will examine two alternative laboratory measurement methods and their correlation to field measurement method(s). For method 1 the reverberant source room will be modified to become a semi-anechoic room and method 2 aims at removing the unwanted reflections of the reverberant room by signal processing. The current paper is only defining field reference cases that are necessary to subsequently assess the applicability of the alternative laboratory methods. The project is performed in collaboration with 4 Danish windows manufacturers: Outline, Krone Vinduer, Living Better and Unik Funkis.

4. WHICH AREA/INDICATOR TO USE FOR CALCULATING THE SOUND INSULATION?

The descriptors typically used to describe the window's sound insulation are the sound reduction indices R and R'_{45°. For objects with a very small area or without a well-defined area the element-normalized level difference $D_{n,e}$. These descriptors are defined as [12] [13]:

$$R = L_1 - L_2 + 10 \cdot \log\left(\frac{S}{A}\right) \quad (1)$$

$$R'_{45^\circ} = L_{1,s} - L_2 + 10 \cdot \log\left(\frac{S}{A}\right) - 1.5 \quad (2)$$

$$D_{n,e} = L_1 - L_2 + 10 \cdot \log\left(\frac{A_0}{A}\right), \quad (3)$$

where L_1 and L_2 are energy average sound pressure levels (SPL) in the source and receiving room respectively in decibels, S is the area of the free test opening which the test element is installed in the lab or area of the test specimen in the field in square meters. A is the equivalent sound absorption area in the receiving room in square meters, A_0 is the reference absorption area (A_0=10 m^2) and $L_{1,s}$ is the average outdoor SPL on the test surface in decibels.

For closed windows there is no doubt regarding which area to use to calculate the sound insulation, but for open windows the choice is not so easy.

For closed windows typically the full area of the window would be used, but for open windows a reasonable choice for S could both be the area of the window or the opening area of the window. Additionally, the element normalized level difference could also be used as descriptor instead of the sound reduction index. Furthermore, for windows with more than one sash and only one or several of them opened, the choice becomes even more complex.

Possible choices for S for a window with more than one sash are shown in Figure 4.

In this paper it is chosen to use S="area of the part of the window which opens" which is the pink rectangle in Figure 4.

Figure 4. Example of possible area S for a window with more than one sash.

5. FIELD CASES

There are a number of different field cases available to study with different types of simple partially open windows. All studied cases in this paper are with loudspeaker as the sound source.

The primary specifications of the field cases are described in Table 1 and Table 2.

Table 1. Window specifications for different field case studies. The cases are defined in Figure 6, which are from 5 sites, where the KO site has several identical windows (however on both ground floor, KO-0, and first floor, KO-1), and where the KA site has both a small window, KA-s, and a big window, KA-b. The types are: TG = top-guided, SH = side-hung, TH = top-hung, DBR = Dannebrog. For both KO and KU the sashes of the window can be opened in different ways and thereby simulate several different types. An example of the sizes and areas are shown in Figure 4.

Case	Type	Wall hole size, m	Size of the open sash, m	Area of open sash(es), m^2	Opening area, m^2	No. of sashes
BR	TG	3.8 x 1.6	1.3 x 1.2	1.59	0.35	1
HO	SH	0.7 x 1.3	0.7 x 1.3	0.94	0.35	1
KO	TH SH	2.2 x 1.4	0.6 x 1.1	0.66	0.30-0.35	4
KA-s	TH	2.1 x 1.2	1.2 x 1.3	1.56	0.35	2
KA-b	TH	2.4 x 2.1	1.2 x 1.1	1.36	0.35	4
KU	DBR	1.0 x 1.6	1.0 x 1.6	1.70	0.35	4
	SH		0.5 x 1.1	0.50		

The field cases differ by the window type, size, area, number of sashes and opening area as well as by the angle and distance of the loudspeaker to the window and the ground type between the test element and the sound source. All the windows were outward opening. The tested windows are shown in Figure 6 and the arrangement of the loudspeaker can be seen in Figure 5.

For project KO the same windows were measured on the ground and first floor, denoted KO-0 and KO-1 respectively. The 4-sashed KO window's 2 upper sashes were top-guided and two lower sashes side-hung. For project KU, measurements with both the standard Dannebrog window with all windows open and supplementary seen as a side-hung window with one of the lower sashes open were performed.

For project BR it is the same window and results as described in [15].

Table 2. Distances between the window center and ground, window and loudspeaker (LS) and ground type for field case studies.

Case	Distance to ground (H_w), m	Horizontal distance to LS (D_l), m	Ground type	Distance to moving LS path (D_{ml}), m
BR	5.0	5.0	asphalt	10/35
HO	5.0	5.7	grass	-
KO-0	2.7	8.4	grass / asphalt	8.4
KO-1	6.5	8.4	grass / asphalt	8.4
KA	4.6	5.0	asphalt	5.0
KU	2.0	5.0	grass	5.0

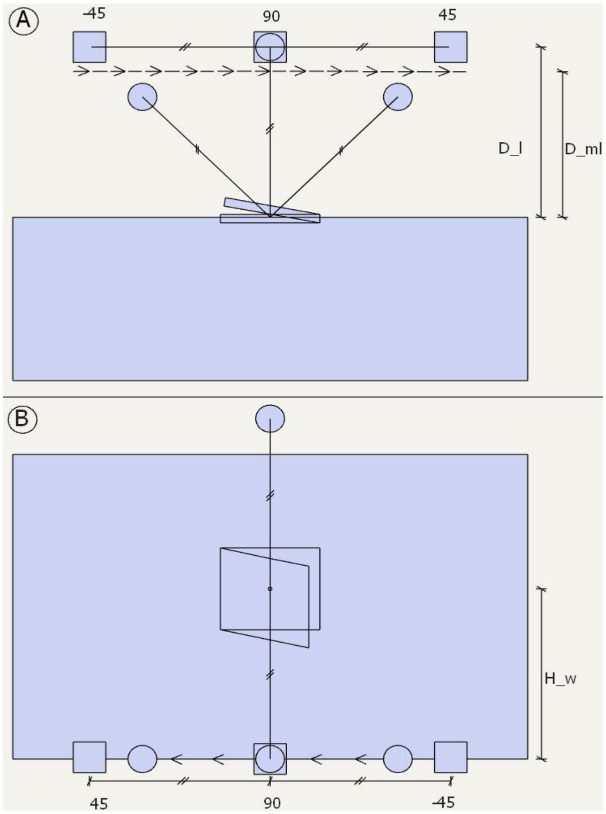

Figure 5. a) Top and b) front view of field measurement loudspeaker positions. Circles – field cases BR and HO. Squares – field cases KO, KA and KU. Arrows – moving loudspeaker.

Figure 6. Photos of the field cases; KO includes both a top-guided and a side-opening window (sashes on the photos are opened more than 0.35 m^2) and for KU both a combination of all windows open and a side-hung open window were measured.

6. RESULTS

For each field case several different measurements were performed, in some situations there was access to windows of different heights. In the following sections results are sorted primarily according to window types (each window type per figure and table in each subsection) and compared with laboratory measurements on similar window types, see Figure 2. The laboratory data is from an earlier project [7]. Secondly, the results are filtered by different other characteristics and shown with colors and line types. It should be noted that the windows in each category are not identical and do not have the exact same sizes, but the purpose is to see if general trends can be identified by looking at the wider picture.

6.1 Dannebrog

For the Dannebrog window type the available data is the field case KU and the laboratory measurement marked M 5006.

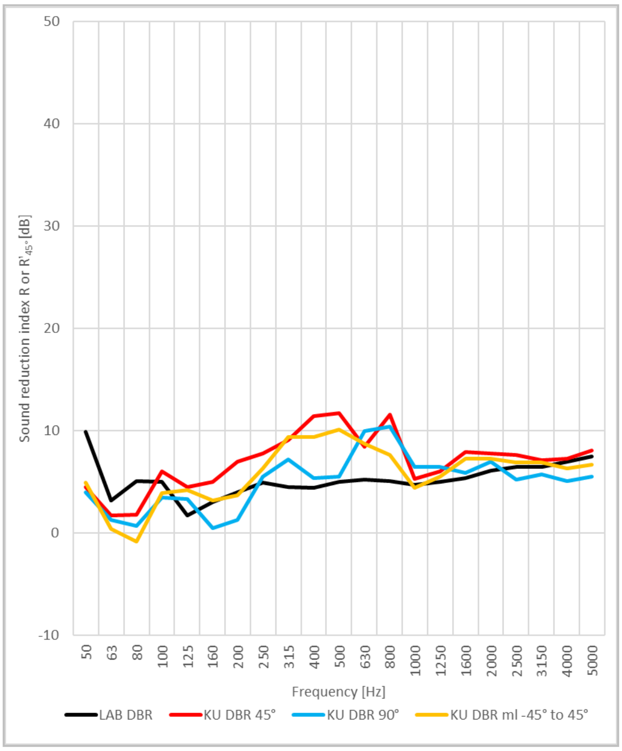

Figure 7. Measured sound reduction indices for open Dannebrog windows. Color-coding relates to Table 3 and loudspeaker position: Black = Lab, Red = 45°, Blue = 90°, and Gold = Moving Loudspeaker.

As seen in Figure 7 and Table 3 the differences between the different sound reduction index curves and single number quantities (SNQ) are relatively small indicating that for this window type with all 4 sashes open the current standardized test methods are applicable.

Table 3. Single-number quantities of airborne sound insulation of open Dannebrog windows. Color-coding relates to Figure 7 and loudspeaker position: Black = Lab, Red = 45º, Blue = 90º, and Gold = Moving Loudspeaker.

Dannebrog	X = R_w | $R'_{45,w}$				X = $D_{n,e,w}$			
	X		X+C_{tr}		X		X+C_{tr}	
	[dB]		[dB]		[dB]		[dB]	
Lab	6		5		13		12	
KU (45º/90º)	8	7	8	6	17	16	17	15
KU ml	7		6		16		16	

6.2 Top-hung & top-guided window

For the category top-hung & top-guided window it is here defined as where the sash is fastened in the top. For this window type the available data is the field cases KA, KO and BR and the laboratory measurement marked M 5004.

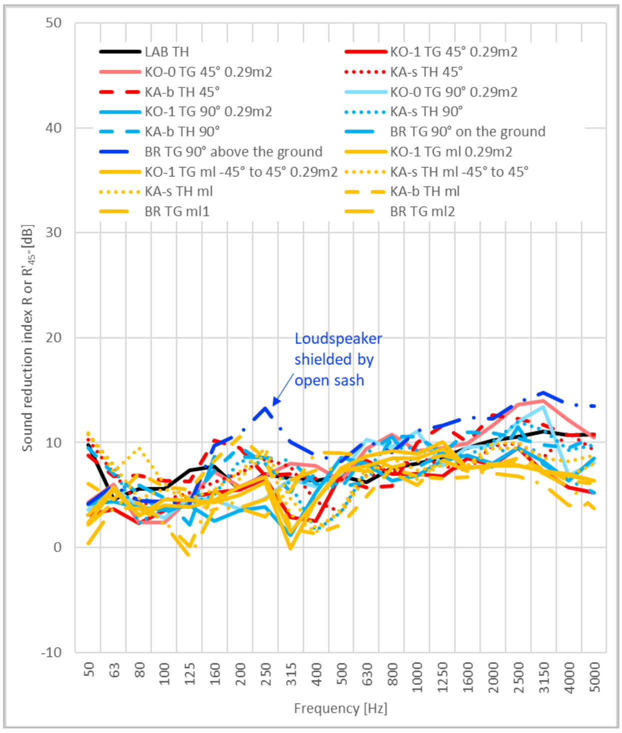

Figure 8. Measured sound reduction indices for open top-hung and top-guided windows. Color-coding relates to Table 4 and loudspeaker position: Black = Lab, Red = 45º, Blue = 90º, and Gold = Moving Loudspeaker. The dark blue is the shielded position in the air.

As seen in Figure 8 and Table 4 the differences between the different sound reduction index curves and SNQ's are mostly again relatively small indicating that for this window type the current methods are applicable. However, all field measurements but one have the loudspeaker placed so that the open sash does not shield the loudspeaker (much). The only exception is the BR case with the loudspeaker in the air, where the open sash shields the loudspeaker, and as can be seen in Figure 8 the shape of the curve (dashed dark blue) is distinctly different than the other curves. These observations support the hypothesis that the current test methods may not be sufficient if the sound source is at a specific direction.

Table 4. Single-number quantities of airborne sound insulation of open top-hung/top-guided windows. Color-coding relates to Figure 8 and loudspeaker position: Black = Lab, Red = 45º, Blue = 90º, and Gold = Moving Loudspeaker. The dark blue is the shielded position in the air.

Top-hung & top-guided	X = R_w | $R'_{45,w}$				X = $D_{n,e,w}$			
	X		X+C_{tr}		X		X+C_{tr}	
	[dB]		[dB]		[dB]		[dB]	
Lab	9		8		16		15	
KO-1 (45º/90º)	7	8	7	6	21	21	20	20
KO-0 (45º/90º)	10	10	9	8	24	23	22	22
KA-s (45º/90º)	8	8	7	7	17	18	17	17
KA-b (45º/90º)	10	9	8	9	20	19	19	19
BR (90º in air/ 90º ground)	11	8	10	8	19	16	18	16
KO-1 ml	8		7		21		20	
KA-s ml	7		6		17		16	
KA-b ml	6		6		16		16	
BR ml	8	7	7	6	16	15	15	14

6.3 Side-hung window

For the category side-hung window it is here defined as windows which are fastened on the side. For this window type the available data is the field cases HO, KA, KO and KU and the laboratory measurements marked M 5003 and M 3316. These results are a bit more complex to interpret. For the side-hung windows the notation 45° is always used for the situation where the sound source is behind the open window, and -45° is used when the sound source is relatively unshielded, see Figure 5. In Figure 9 and Table 5 the unshielded noise source results (-45) are marked with green and the shielded noise source results (45) are marked with red. There is a distinctive difference between the green and red curves, especially for higher frequencies than 250 Hz. This is also reflected in Table 5, where the difference is 4-5 dB for R_w | $R'_{45,w}$ and 3-4 dB for R_w | $R'_{45,w}$ + C_{tr}.
The 90° position and the moving loudspeaker are marked with respectively blue and gold color, and are in general between the red and green curves.
The best correlation to the laboratory results seems to be the 90° and moving loudspeaker results, again supporting the hypothesis that the current test methods may not be sufficient if the sound source is at a specific direction.

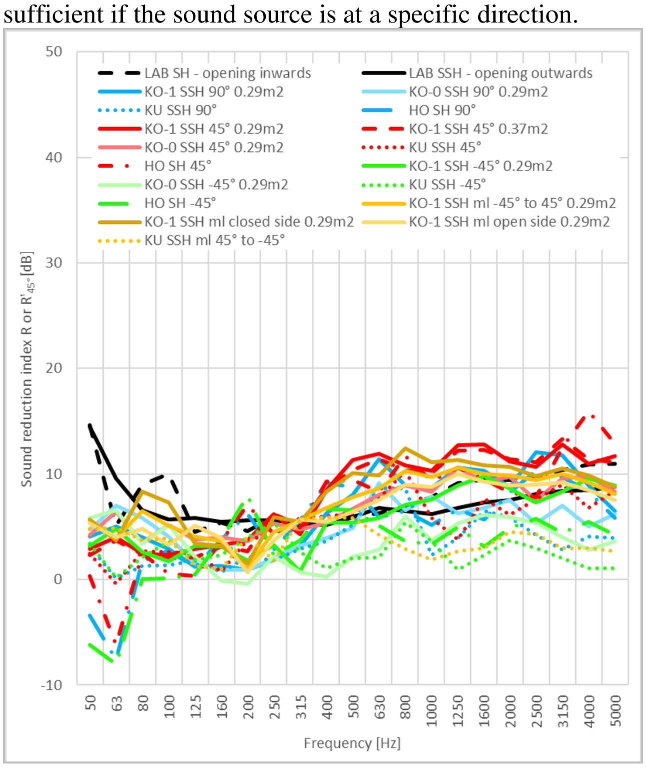

Figure 9. Measured sound reduction indices for open (split) side-hung windows. Color-coding relates to Table 5 and loudspeaker position: Black = Lab, Red = 45°, Blue = 90°, Green = -45° and Gold = Moving Loudspeaker.

Table 5. Top: Weighted sound reduction indices for open side-hung windows. Bottom: Weighted element-normalized level differences for open side-hung windows. Color-coding relates to Figure 9 and loudspeaker position: Black = Lab, Red = 45°, Blue = 90°, Green = -45° and Gold = Moving Loudspeaker.

Side-hung	X = R_w | $R'_{45,w}$					
	X			X+C_{tr}		
	[dB]			[dB]		
(Lab M5003)	8			7		
Lab M3316	7			7		
KO-1 (45°/90°/-45°)	11	9	7	9	7	6
KO-0 (45°/90°/-45°)	9	7	4	8	6	4
HO (45°/90°/-45°)	10	8	5	8	6	4
KU (45°/90°/-45°)	7	5	3	6	4	3
KO-1 ml	9			8		
KU ml	4			3		

Side-hung	X = $D_{n,e,w}$					
	X			X+C_{tr}		
	[dB]			[dB]		
(Lab M5003)	16			15		
Lab M3316	14			14		
KO-1 (45°/90°/-45°)	24	23	21	23	21	19
KO-0 (45°/90°/-45°)	22	20	18	21	19	17
HO (45°/90°/-45°)	20	18	15	19	16	14
KU (45°/90°/-45°)	22	20	17	20	19	17
KO-1 ml	23			21		
KU ml	18			18		

7. CONCLUSION

This paper describes the background of the MEÅV project and the studied reference field cases. The comparison between field and laboratory is not on identical test windows, and as such the conclusions should be treated with some care, but so far, the hypothesis of too conservative results in the laboratory for simple partially open windows utilizing geometry seem to be justified.
Next steps would be to find a reference case with an example of a simple partially open window utilizing geometry, which should be measured both in the field and in the laboratory, and to develop and test alternative laboratory methods.

8. ACKNOWLEDGMENTS

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