Giants of Sampling 3: Sylvanus Albert Reed

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DOI: 10.62178/sst.003.006

EDITOR'S NOTE

Nowadays, Alan is on his own recognizance but scientifically is not at all retired. He continues his magisterial series on "Giants on Sampling" this time on the history of one of sampling's lesser known (very) early initiators.

1. The very first step towards representative sampling?

S(ylvanus) Albert Reed's claim to fame is that he probably laid down in print the first mathematical formula concerning representative sampling. As such he must certainly be counted among the founding fathers of what later came to be known as the Theory of Sampling (TOS). We'll deal with this formula in a later section, noting that this contribution was minor in respect of all else he achieved. We can compare him with Brunton (Giants of Sampling #2, in SST#2) in many ways possessing a wide range of skills and accomplishments. He made his money in a field outside mining (some cynics would claim that making a fortune in mining isn't possible). He bridged the academic Holy Grail: From an initial degree in arts, his course took him through science and engineering and into the money. Initially he pursued a career in mining, but this gave way to work in the insurance field, electrical signaling for railways, and general chemistry patenting, specifically an invention in generating electricity from coal gas culminating in the invention of the first sustainable metal aircraft propeller. Like Brunton (see issue 2 of SST), he patented then defended his patents extensively. In the compilation of literature available, his preferred form of address was S. Albert Reed, so we can deduce that (like many others) he was not fond of his given first name and preferred Albert (or perhaps Bert/Bertie?).

2. Family

Sylvanus Albert Reed was born on the 8th April, 1854, in Albany, New York, United States. His father was the Reverend Sylvanus S. Reed (13th July, 1821 – 16th October, 1870) and his mother was Caroline (Gallup) Reed.

Sylvanus Albert Reed was married only once (when he was an insurance executive) and, sadly, the duration was short-lived as his wife, Elmina Wilshire Pomeroy (known as Ella or Ellen) died just after their second anniversary.

3. Education

We are lucky to be able to trace Reed's education and early career through Alumni publications of the Columbia School of Mines. Prior to college, he was educated in various public and private schools including Albany Academy and several New York schools. Eventually he obtained five degrees!

- AB (1874) – an arts undergraduate degree, Columbia University
- AM & ME (1877) – degrees from the School of Mines, Columbia University
- Ph.D. (1880) "The investigation of Professor Mayer's method of locating wave surfaces in media surrounding sounding bodies", Columbia University
- D.Sc (1929) – this was honorary in relation to his later aeronautic/propeller work

The Columbia University Class of 1874 Yearbook contains two wonderful pictures of Reed aged around 20 (Fig.1). In 1899, at the 25th Anniversary reunion provides another picture of Reed aged around 45 years old (Fig 2).

He made his contribution to sampling with two papers, one in 1882 and the other in 1885. However, in 1886 he made a switch from mining to Insurance Engineering, which appears to be quite a move. He specialized in electrical signals for railroad safety and patented extensively in this period. His major insurance work was the classic report on the 'San Francisco Fire/Conflagration (1906)', which followed the earlier earthquake.

1 Retired. Hardwick, Massachusetts, USA.

Figure 1: Photos of Sylvanus Albert Reed (age ~20) at Graduation. Courtesy of Columbia University Archives.

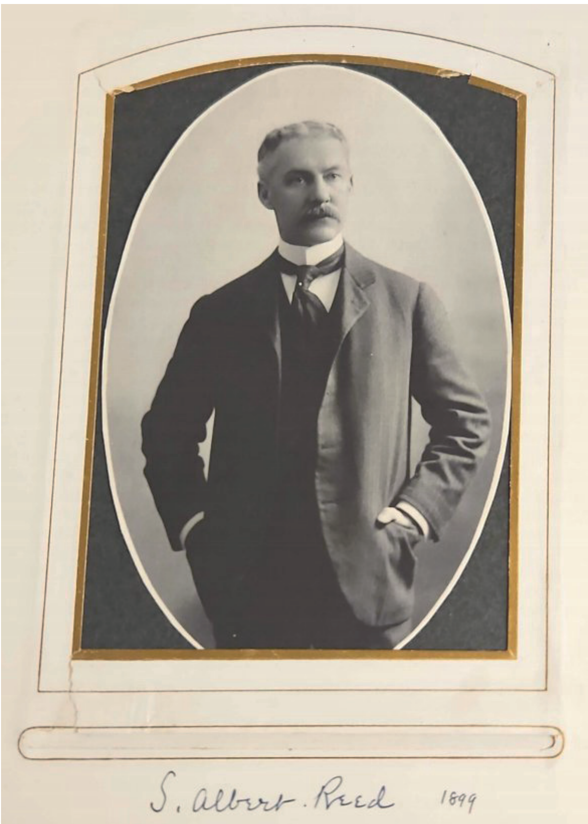


Figure 2: Sylvanus Alvert Reed at the 1899 college Class Reunion (age ~45). Courtesy of Columbia University Archives.

4. Sampling

Sylvanus Albert Reed published two papers on sampling in The School of Mines Quarterly in 1882 and 1885 respectively, surprisingly not based on his Ph.D. thesis of 1880. Although he had no further academic activity in the field, he held some jobs in mining and sampling works that are documented in the Columbia University Alumni publications before his move into insurance.

5. In medias res

His first paper in 1882, entitled simple "Ore Sampling", is a just a little over seven pages long. It is rather general and descriptive. Early on he remarks, prescient to Pierre Gy, "Exact sampling must be assured, or a bid becomes merely a bet". He further states that "the subject (*sampling*) has been more scientifically studied and carried nearer perfection in Colorado than anywhere else". This indeed reflects the emphasis on gold and silver ores in the mining papers around that time. He takes around three pages to describe his preferred method (probably used when he was employed in the field) involving crushing and (split) shoveling reducing 10 tons to 1 ton, eventually ending up with three samples (buyer, seller, referee/umpire) passing 80 mesh (~ 180 microns) of about ¾'s of a pound (~ 340 g).

He displays a figure illustrating the 'automatic part' of his sampling process from which it is quite clear that this type of riffling process is subject to what TOS today would label as 'delimitation errors':

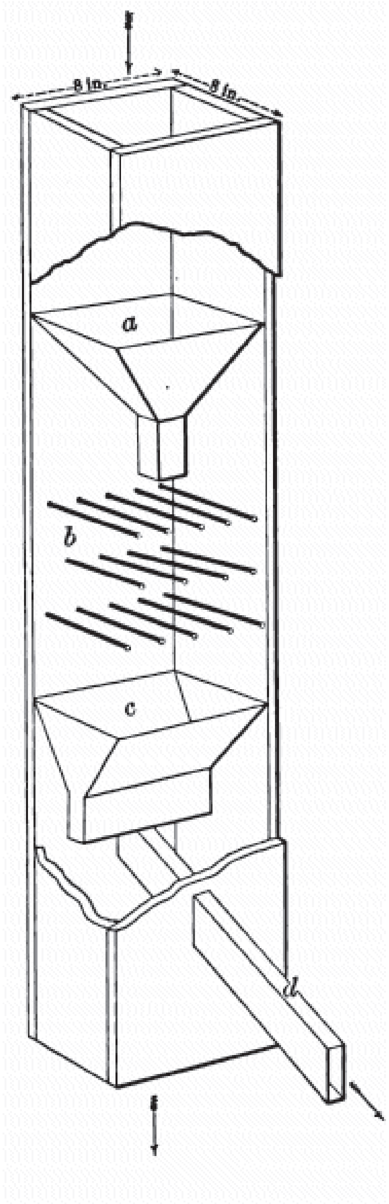


Figure 3: The "Reed 1882 Automatic Sampler"

We are informed that the rods ('b' in the diagram) are there to "thoroughly mix the starting material" while at the bottom of chute 'c' one-tenth of the material is extracted only from the center of the chute along the inclined plane, 'd'. This is where the claim to 'representative sampling' is certainly not justified. Reed comments "It would be an interesting problem to work out mathematically from the doctrine of *chances*, the principles of good sampling of an irregular mixture".

He explores this mathematics in his 1885 paper. However, in his 1882 paper, Reed gives four fundamental points regarding sampling that can be summarized as:

- A certain maximum limit in the sample to the ratio between coarseness and quantity (of sample to be extracted). This is related to the top particle size (x_{95} or x_{99} in modern literature)
- Minimum mass of sample to be extracted from the whole
- No selectivity in sampling – "free from any tendency to select one set of particles at the expense of others
- Thorough mixing, and no tendency for sorting

The 1885 paper: "More remarks on Ore Sampling" begins by stating three important principles:

1. Adequate mixing
2. Impartial selection
3. Proper relative comminution

He then states the important maxim: "In fact, it may be stated that the probable error in properly conducted ore sampling operations is less than the probable error of the assay of the sample when obtained", a fact 'known' ('felt') to be true for many years.

Reed describes a number of forms (modes) of sampling from quartering to mechanical means concluding that of the mechanical methods "*The latest and best is that of Mr. Brunton, described in a recent paper read before the Am. Inst. of Mining Engineers*". However, he is also quick to criticize Brunton: "*Mr. Brunton, by the way, in his paper makes the misleading statement that the bulk of Colorado ore is sampled mechanically, whereas I will venture to say that 3/4 of the ore product of that State is sampled by hand*", a personality trait (mild autism/Asperger's)? that we can observe throughout his literature and interactions with authorities. Reed then begins the most important part of this landmark paper by stating:

The divergence of any portion of a lot of ore from the average percentage composition of the whole is due to the excess or deficit of one or more particles. The effect upon the result will be greatest when the pieces causing this divergence are of the largest size and richest quality.

He then defines a number of terms:

p = the quantity of the lot (in Troy ounces)
f = the number of parts into which we divide before selecting one as sample
k = percentage (of silver or gold in the *richest* specimens in the lot)
s = sp. gr. of the same
m = the *grade* of the ore in ozs., per ton
D = diameter of *largest pieces* in the lot in inches
a = the number of pieces of size D, and k value, that can be in excess or deficit in the portion chosen for sample

Working in the above units provides some conversion difficulties. However, Reed does end up with a practical formula:

Most samplers will agree that ore of a pretty good grade, say 100 ozs., and quite irregular, say carrying 3000 oz. specimens, may be cut down from 1 ton to 20 lbs. without crushing finer than ¼ inch, and that the error likely to occur is within 1% of the result, a very fair allowance for assay error. Substituting we get

$$a = 1.6 \text{ . and } D = .042 \sqrt[3]{\frac{m\,p\,l}{s\,k\,(f-1)}}$$

a theoretical expression that we can venture to apply to other cases.

Figure 4: The "Reed Formula 1885"

He is then able to provide an important summary table indicating the particle size to which certain ores need to be comminuted (see Fig. 5).

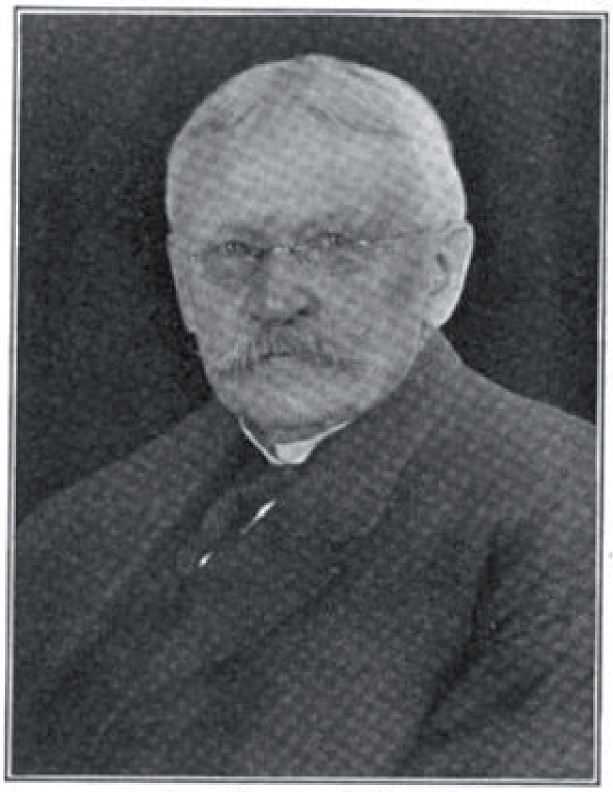
We note the reduction starting from 100 tons down to 5 pounds and then ground below a certain mesh size for a laboratory assay sample. This is the classic chart and was used for the basis of a very similar chart in various of Heinrich O(scar) Hofman's texts. Hofman was the second MIT mining professor after the first, Robert Hallowell Richards, who will be the next Giant of Sampling in this series.

It is interesting to note Hofman's estimated costs and their breakdown for the summer school. The Board and Lodging is attributed to $1.50/day for 24 days making a total of $36, while the rail fares for the journeys including to and from Boston total $35. Washing and sundries make up $9. One wonders what comparable costs would be nowadays.

Hofman is responsible for attributing some important sampling generalities to Henry Vezin: "Vezin, in 1866, finding that with pyritic ores of Gilpin County, Colo. , running from 1 to 4 oz. of gold per ton, it was safe to cut down to 1 oz. a sample that had passed a 20-mesh screen, the diameter of the largest particle being 1 mm (1/25 inch) prepared the following table for this class of ores" (see Fig. 8).

For general purposes. $s = 7$ $l = 1$	Medium galena and carbonate ores, free from rich minerals. Ore averages about 50 ozs. = *m*. Best specimens assay about 300 ozs. = 1% = *k*.	Medium grade gray copper chloride, ruby silver, etc., ores. *m* = about 75. Specimens assay up to 3000 ozs. per ton, ∴ *k* = 10.	High grade ores, carrying rich minerals, for example, *m* = 500. Specimens assay up to 10,000 ozs. per ton, ∴ *k* = 30.
Reducing 100 tons to 10 tons by taking 10th shovel (shovel sample).	*D* = 5.28" Pieces larger than cocoanuts must be broken up.	*D* = 2.96" Pieces larger than the fist must be broken up.	*D* = 2.58" Pieces larger than the fist must be broken up.
Reducing the 10 tons to 1 ton. (quartering sample).	*D* = 2.46" Break the lot to about size of oranges.	*D* = 1.38" Break to about egg size.	*D* = 1.2" Break to walnut size.
Reducing the 1 ton to 200 lbs. (wheelbarrow sample).	*D* = 1.14" Break to about walnut size.	*D* = 0.6" Crush in rolls to chestnut size.	*D* = 0.56" Crush in rolls to about chestnut size.
Reducing the 200 lbs. to about 5 lbs. (pan sample).	*D* = 0.3" Crush in rolls to pea size.	*D* = 0.18" Crush in rolls to size of wheat.	*D* = 0.16" Crush in rolls to the size of wheat.
Reducing the 5 lbs. to a sample from which portions can be taken directly for assay, *i. e.*, 1–10 A. T. (bottle sample).	*D* = 0.034" Grind to 20 mesh.	*D* = 0.02" Grind to 25 mesh.	*D* = 0.018" Grind to 50 mesh.

Figure 5: Size to which various ore types need to be comminuted – "The Chart"



PROF. HEINRICH O. HOFMAN.

Figure 6: Heinrich Hofman

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

April 2, 1895.

DEAR SIR: Professor Richards being prevented from taking charge of the Summer School of the Mining Department, the duty falls upon the undersigned. The school is held alternately at mining and metallurgical centers. This year mainly metallurgical works will be visited and incidentally some mines. The school will be held in New Jersey and Pennsylvania where the metallurgy of copper, lead, silver, zinc, iron and steel and the manufacture of sulphuric acid will be studied and a coal and an iron mine visited. The party will start not later than May 28 by the Fall River line for New York city, will visit Bergenport, Jersey City and Newark, N. J., and Lebanon, Steelton, Everett and Johnstown, Pa. The school will last from twenty-one to twenty-four days, closing at Johnstown. The expense including return to Boston is estimated to be:—

Railroad Fares	$35.00
Board and Lodging, 24 days at $1.50 .	36.00
Washing and Sundries	9.00
	$80.00

All members of the party are expected to remain until the close of the Summer School. You are cordially invited to attend. Please reply before April 27th.

H. O. HOFMAN.

Figure 7: Summer school costs after Hofman (source unknown)

Diameter of Piece, Mm.	1	2	4	8	16	32	64
Diameter of piece, Inches	1/25	1/12	1/6	5/16	5/8	1 1/4	2 1/2
Minimum weight of sample, pounds	1/16	1/2	4	32	256	2,048	16,348

With richer ores, of course, it would be necessary to increase the weight of the sample.

Figure 8: Vezin's Table (according to Hofman)

Quantity of Ore. Reducing	Value of Silver in Ounces Per Ton.			Size of Ore.
	Highest: 300. Average: 50.	Highest: 3000. Average: 75.	Highest: 10,000 Average: 500.	
100 tons to 10 tons	Cocoanut	Fist	Fist	Maximum permissible size of ore for given grade.
10 tons to 1 ton	Orange	Egg	Walnut	
1 ton to 200 pounds	Walnut	Chestnut	Chestnut	
200 pounds to 5 pounds	Pea	Wheat	Wheat	
5 pounds to bottle-sample	20-mesh	25-mesh	50-mesh	

Figure 9: Hofman's summary of Reed's original table

It seems unlikely that this work can date back as far as 1866 given that Vezin was living in Philadelphia at that time and had not yet moved west to Colorado. Hofman then talks of Reed's calculation and provides a smaller and amended table to that of Reed's above (see Fig. 9).

Hofman further expands the discussion by working with some of Brunton's material that was discussed in the "Giants of Sampling 2" article. He shows a table developed for him by a certain Mr. Fr. Drake showing the minimum weights of sample needed for crushing different ore types as examples (pyrites, silver, gold – see Fig. 10).

Special Gravity Richest Mineral	Size of Particles.		Safe Weight in Pounds for Sample whose Largest Particles are of Size given in Second Column.								
	Mesh.	Diameter. Inches.	Grade of Richest Mineral Divided by Average Grade.								
			10	50	100	400	700	1000	1500	2000	2500
5.0	120	.0043				.0051	.0089	.0128	.0193	.0257	.0334
	100	.0055	.00023	.00127	.0025	.0103	.0181	.0259	.0389	.0518	.0674
	20	.027	.0248	.1352	.273	1.1	1.9	2.7	4.1	5.5	7.1
	8	.062	.279	1.5	8.	12.	21.	81.	46.	62.	80.
	4	.145	2.81	15.	30.	124.	218.	312.	468.	624.	812.
	2	.338	30.	163.	330.	1331.	2331.	3339.	5000.	6668.	8670.
		.5	78.	429.	868.	3501.	6133.	8766.	13153.	17541.	22806.
		1.	486.	2646.	5346.	21546.	37746.	53946.	80946.	107946.	140346.
		2.	3888.	21168.	42768.	172368.	301968.	431568.	647568.	863568.	1122768.
		4.	81104.	169344.	342144.	1378944.	2415744.	3452544.	5180544.	6908544.	8982144.
7.5	120	.0043				.01156	.02026	.0289	.0434	.0579	.0724
	100	.0055	.00054	.00295	.00597	.0241	.0421	.0602	.0904	.1205	.1507
	20	.027	.0572	.3116	.6296	2.5	4.4	6.3	9.5	12.7	15.
	8	.062	.621	3.3	6.8	27.	48.	08.	103.	137.	172.
	4	.115	6.2	33.	68.	276.	483.	691.	1037.	1383.	1729.
	2	.338	61.	337.	681.	2745.	4810.	6875.	10316.	13757.	17198.
		.5	145.	793.	1603.	6463.	11323.	16183.	24283.	32383.	40483.
		1.	729.	3969.	8019.	32319.	56619.	80919.	121419.	161919.	202419.
		2.	5832.	31752.	64152.	258552.	452952.	647352.	971352.	1295352.	1619352.
		4.	46611.	253770.	512721.	2066421.	3620121.	5173821.	7763321.	10353821.	12942821.
10.5	120	.0043		.00287	.0058	.0234	.04096	.0585	.0878	.1171	.1464
	100	.0055	.00109	.00599	.0121	.0487	.0854	.1221	.1832	.2443	.3054
	20	.027	.1103	.6007	1.21	4.8	8.5	12.	18.	24.	30.
	8	.062	1.17	6.3	12.8	51.	91.	130.	195.	260.	325.
	4	.145	11.4	62.	126.	509.	891.	1274.	1912.	2550.	3188.
	2	.338	110.	600.	1213.	4891.	8569.	12247.	18377.	24507.	30637.
		.5	242.	1319.	2665.	10742.	18819.	26896.	40357.	53819.	67280.
		1.	1020.	5556.	11226.	45246.	79266.	113286.	169986.	226686.	283386.
			2000	10000	15000	20000	25000	30000	40000	50000	60000
17.6	120	.0043	.181	.9059	1.3	1.8	2.2	2.7	3.6	4.5	5.4
	100	.0055	.37	1.88	2.8	3.7	4.7	5.6	7.5	9.4	11.3
	20	.027	37.	189.	285.	380.	475.	570.	760.	950.	1140.
	8	.062	397.	1989.	2985.	3980.	4975.	5970.	7960.	9950.	11940.
	4	.145	3818.	19098.	28650.	38200.	47750.	57300.	76400.	95500.	114600.
	2	.338	35202.	176082.	264150.	352200.	440250.	528300.	704400.	880500.	1056600.

Figure 10: Hofman's Table based on Brunton calculations

Obviously, this is a fairly complex table. The rest of Hofman's sampling chapter deals with the classic sampling methods – quartering, shoveling (split and alternate), various types of riffler device (e.g., Jones) and mechanical samplers of the Bridgman, Constant, Brunton, and Vezin varieties.

A similar table derived from Reed's calculations is displayed in the Clennell's 'The Cyanide Handbook' (1915), indicating that it had influenced mining sampling for at least 30 years (Fig. 11).

The following table is given for ores of different grades, assuming in all cases that $s = 7$, $l = 1$, and that with samples:

Class A,	m = 50	k = 1	Medium,
" B,	m = 75	k = 10	high-grade,
" C,	m = 500	k = 30	very rich.

Table II

Sample Reduced from	Value of D, in Inches		
	Class A	Class B	Class C
100 to 10 tons	5.28	2.96	2.58
10 to 1 ton	2.46	1.38	1.2
2000 to 200 lbs.	1.14	0.6	0.56
200 to 5 "	0.3	0.18	0.16
5 lbs. to 10 assay tons	0.034	0.02	0.018

Figure 11: Table from the 'Cyanide Handbook' following Reed's method and formulae

The last line in this table ("5 lbs. to 10 assay tons") is an *obvious misprint* and should probably read 5 pounds to 10 ounces (oz.).

Clennell had given an earlier table, attributed to Alfred Harvey (Fig. 12), which was published in Mining and Scientific Press Volume LXVIII (88) in January 1904 (Fig. 13).

Table I. — Allowable Sizes of Ore Pieces in Sampling

Diameter of Largest Pieces in Sample: Inches	Minimum Weight of Sample: Pounds	Diameter of Largest Pieces in Sample: Inches	Minimum Weight of Sample: Pounds
5½	79,300	2/3	256
4	69,109	1/3	32
3½	44,958	1/6	4
2½	16,384	1/12	½
1¼	2,048	1/25	1/16

[1] "Min. and Sci. Press," LXXXVIII, p. 78 (Jan. 30, 1904).

Figure 12: Clennell's table (attributed to Harvey) in the 'Cyanide Handbook'

Diameter of Largest Pieces: M.M.	Inches (Approximate).	Minimum Weight of Sample.
1	1/25	1 ounce
2	1/12	½ pound
4	1/6	4 pounds
8	1/3	32 pounds
16	2/3	256 pounds
32	1¼	2,048 pounds
64	2½	16,384 pounds
..	3½	44,958 pounds
..	4	69,109 pounds
..	5½	79,300 pounds

Figure 13: Alfred Harvey's Table from MSP Volume 88 1904

Figure 14: March 19, 1926. Orville Wright (far right), chairman of contest committee of National Aeronautic Association, presents the Collier Trophy for 1925 to Dr. S. Albert Reed (second from right), aeronautical engineer, in ceremony at Bolling Field, Washington, D.C. Picture Courtesy of Wright State University Libraries' Special Collections and Archives.

6. Moving into aviation

Reed retired from insurance engineering on October 31st, 1912 (aged 58) and moved into aviation via an attempt to invent a better foghorn. This 'foghorn' turned out to be a route to make an all metal, durable propeller which proved excellent for high-speed applications. There were many wins in the historical Schneider and Pulitzer Trophy events with his design, especially when paired with the Curtiss D-12 engine plus air speed records in the 1920s and 1930s.

All this work led to Reed being awarded the Collier Trophy in 1925, which is awarded annually for "the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, and safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year" (From Wikipedia).

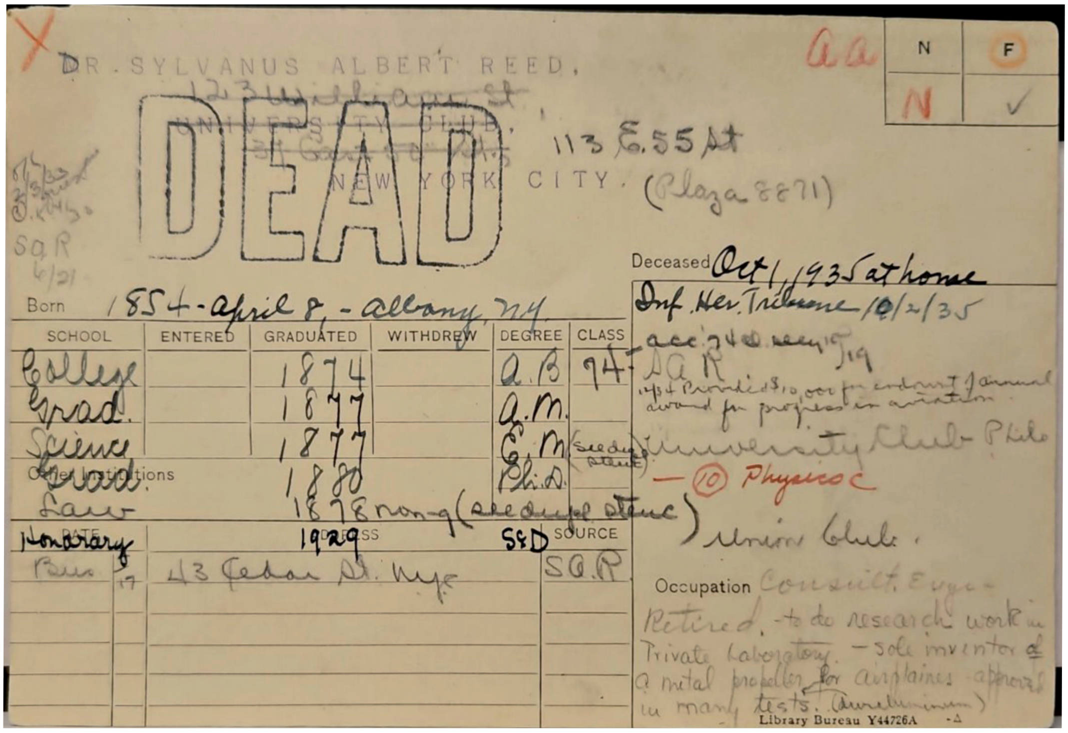
Figure 15: Presentation of the 1925 Collier Trophy to Reed by Orville Wright, Bolling Field, March 19, 1926. From *Aviation* April 19, 1926, Page 605.

7. Legacy

Reed bequeathed to the Institute of the Aeronautical Sciences (IAS) ten thousand dollars ($10000) to endow the "Sylvanus Albert Reed Award". A cash award of the sum of $250 would be awarded annually and Reed himself wrote the first check on Thursday January 30th, 1934. This award (now called the Reed Aeronautics Award) is considered the "highest honor an individual can receive for a notable achievement in aeronautics that represents a significant engineering advancement milestone". The approximate value of $250 USD in 1934 is approximately $6,000 in 2024, and $10000 in 1934 is worth around $250,000 USD today.

Sylvanus Albert Reed died on 1st October 1935 after a "short illness". He is buried with his parents and wife in All Saints Memorial Church Cemetery, Navesink, Monmouth County, New Jersey, USA (Plot: Section 1E, Lot 12).

Below we end this exposé with his Columbia University Alumni Federation card (with the poignant stamp "Dead" on it) that includes an obituary on the right:


DR. SYLVANUS ALBERT REED,
UNIVERSITY CLUB,
NEW YORK CITY.
DEAD
113 E. 55 St
(Plaza 8871)
N F
N ✓
Deceased Oct 1, 1935 at home
Born 1854 - April 8, - Albany, N.Y.

SCHOOL	ENTERED	GRADUATED	WITHDREW	DEGREE	CLASS
College		1874		A.B.	74
Grad.		1877		A.M.	
Science		1877		E.M.	
Grad		1880		Ph.D.	
Law		1878 non-g			

Other Institutions
DATE | ADDRESS | SOURCE
Honorary | 1929 | S&D
Occupation Consult. Engr.
Retired, - to do research work in Private Laboratory. - Sole inventor of a metal propeller for airplanes
Library Bureau Y44726A

Figure 16: Columbia University Alumni Federation Card "Dead". Courtesy *Columbia University Archives.*

ACKNOWLEDGEMENT

This article has moved on greatly from the material that was first presented as a webinar in 2012 (sadly no longer available). More material has come to light and I in particular would like to thank Jocelyn Wilk of the Columbia University Archives for going the extra mile and digging up excellent pictures of Reed aged 20 in 1874 and 45 in 1899. This article is probably the first time these pictures have seen the literary light of day. I would also like to thank Grace Ethier of Wright State University for tracking down two pictures that appeared in AAHS Journal – pictures of the 1925 Collier Trophy presentation are rarer than hen's teeth, it appears.

References

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H. O. Hofman (1899). *The Metallurgy of lead and the desilverization of base bullion, 5th Ed.*, The Scientific Publishing Company. Other editions of this text contain varying amounts of information relating to sampling.

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Insurance:

S. Albert Reed (1906). 'The Great Fire in San Francisco: The San Francisco Conflagration of April 1906': special report to the National Board of Fire Underwriters, Committee of Twenty (April.)

Propeller/airscrew material:

S. Albert Reed (1922). Technical Memorandum 168 – Washington (November).

Roger Ward (1958). *The Propeller Pioneer Flying*, December, pp. 30 - 31, 74, 76, 78.

Clearly Roger Ward was at the 1926 dinner dealing with the award of the Collier Trophy in 1925 to S. Albert Reed. As the Flying article was published in 1958, it's likely that Roger was fairly old at this time. It contains many personal reminiscences and details the early history of Reed's interactions with the Curtiss staff at Langley Field.

S. Albert Reed (1928). Technical Development of the Reed Metal Propeller Paper AER-50-25 Presented at the National Meeting of the A.S.M.E. Aeronautic Division, Detroit, MI. June 28 and 29, 1928.

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Terry Gwynn-Jones (1991). *Farther and Faster Aviation's Adventuring Years 1909 – 1939*, Smithsonian Institution Press. Provides details of the air races and competition in the 1920s.