Aug. 6, 1963 S. DOBRIN ETAL 3,099,963

OUTWARD BURNING NEUTRAL GRANULATION FOR CAST PROPELLANTS

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Fig. 1.

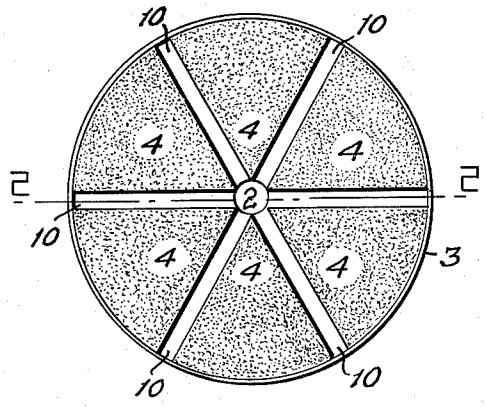


Fig. 9.

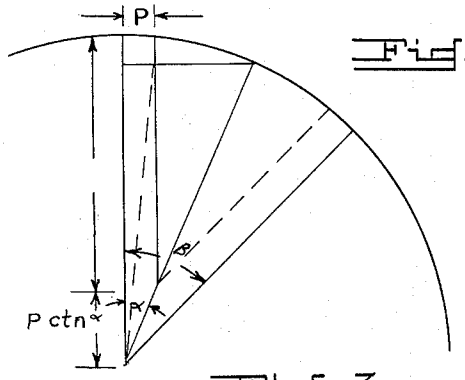
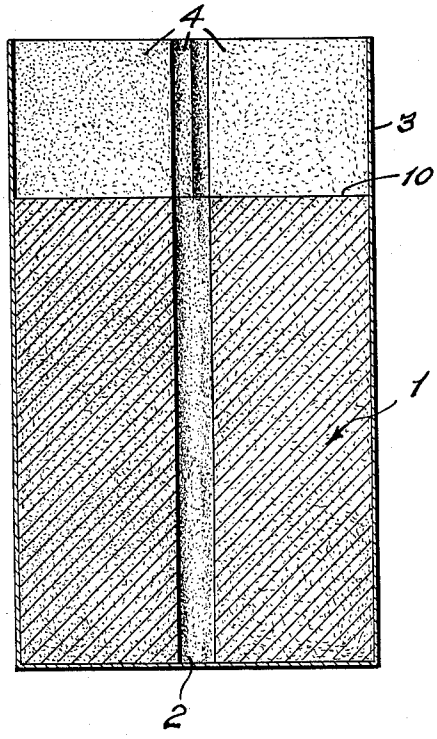
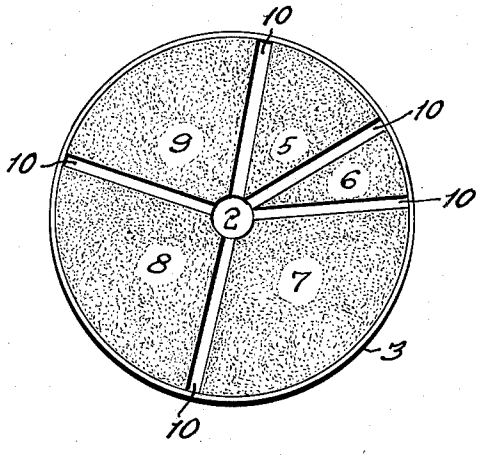


Fig. 3.

Fig. 2.





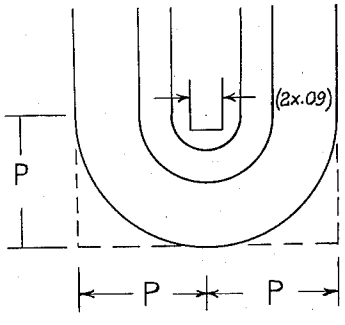


Fig. 10.

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OUTWARD BURNING NEUTRAL GRANULATION FOR CAST PROPELLANTS

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Fig. 4.

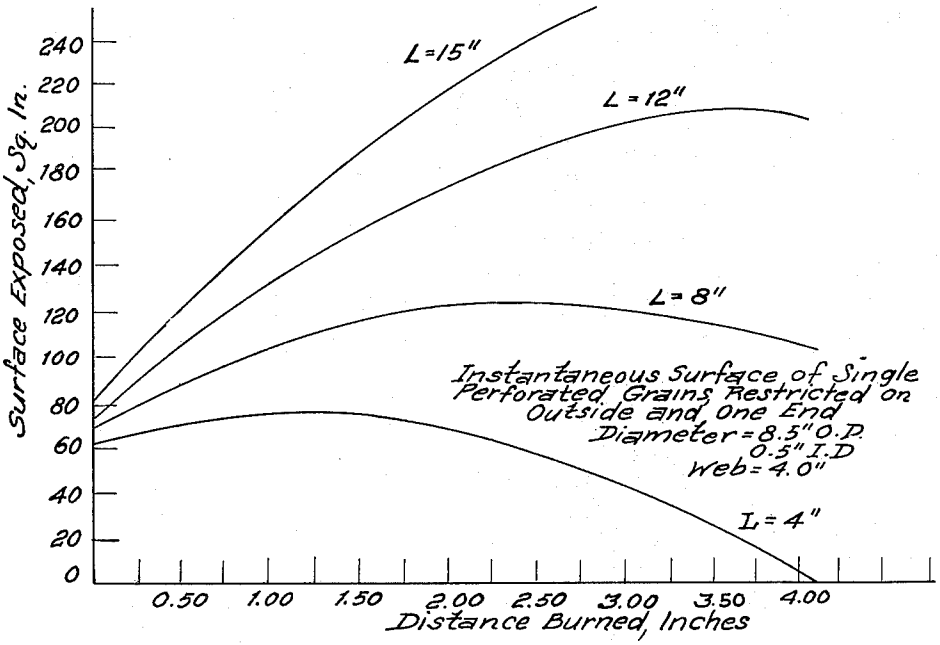


Fig. 5.

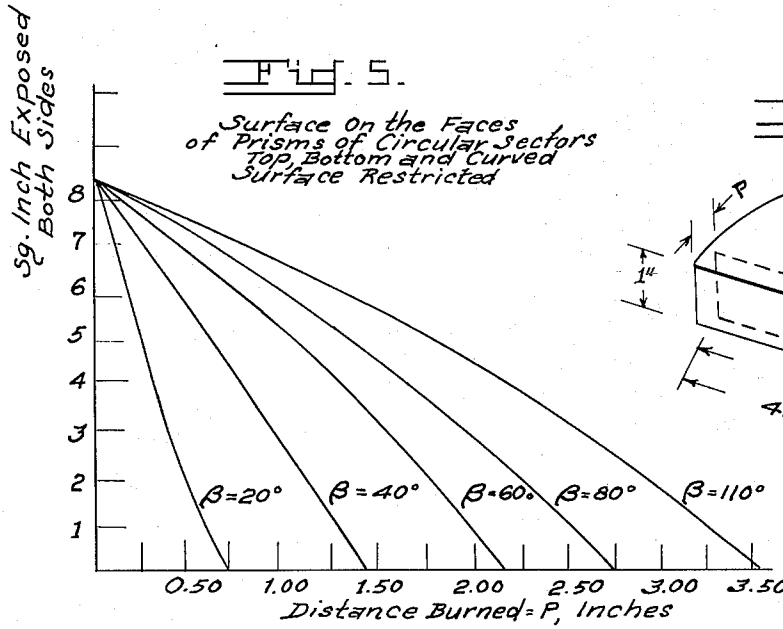
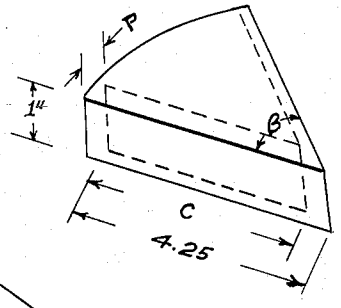


Fig. 6.



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Fig. 7.

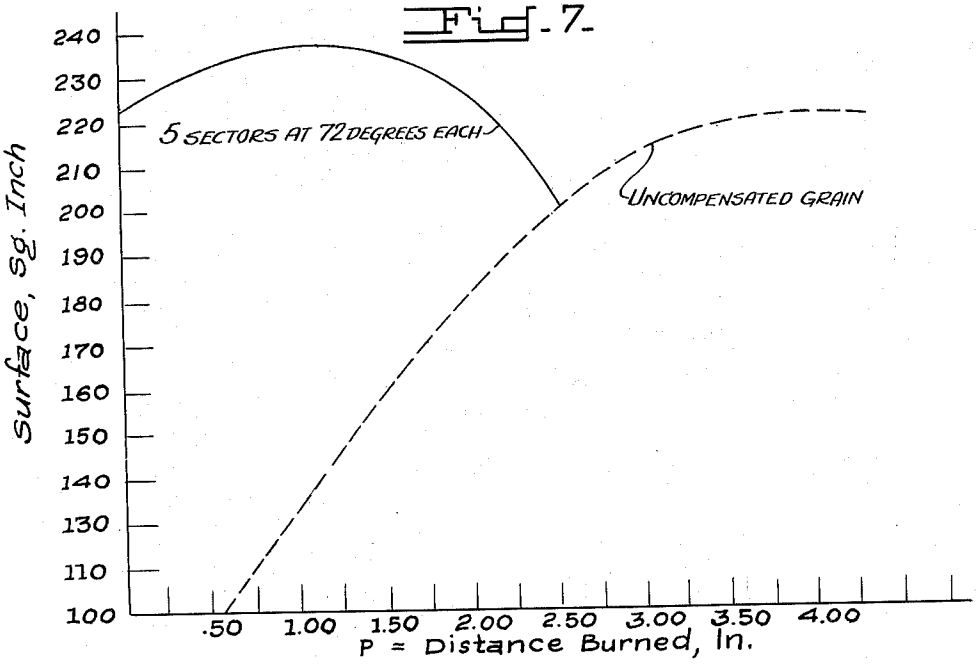
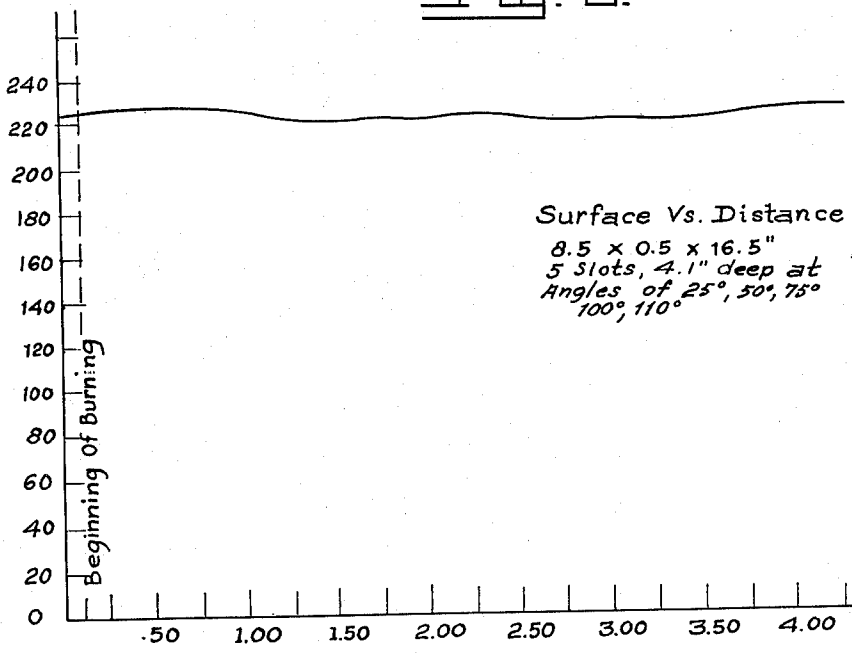


Fig. 8.



Surface Vs. Distance Burned
8.5 x 0.5 x 16.5"
5 Slots, 4.1" deep at
Angles of 25°, 50°, 75°
100°, 110°

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OUTWARD BURNING NEUTRAL GRANULATION FOR CAST PROPELLANTS

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13 Claims. (Cl. 102—98)

This invention comprises a new and improved outward burning neutral granulation for cast propellants.

It is well known that the shape of an explosive propellant grain has a considerable effect on its burning rate. Rodman, about the middle of the nineteenth century, developed the perforated cylindrical grain burning partially from the inside out. Since his time single or multiperforated grains have been standard. Gathmann in Patent 660,568 discloses several such grains. Walsh in Patent 1,077,320 shows another example of the multiperforated type, the rosette, burning more nearly completely than the ordinary multiperforate powder. The burning rate can also be controlled by means of restrictive coatings placed on selected portions of the surface. These coatings prevent burning of the areas covered.

The evolution of gas and hence the propulsive force of the propellant is dependent on the burning rate. A solid grain of any shape will burn with a continuously decreasing surface and burning rate with consequent loss of pressure. This is known as degressive burning. A single perforation such as Rodman first used will allow burning from the inside out. The internal area in this case will increase at just about the same rate as the external will decrease. Constant evolution and pressure of gas results and the grain and burning are termed neutral. Progressive burning occurs when multiple peforations are employed, that is, the exposed surface will continually increase with increased evolution of gas and pressure. Restrictive coatings change the burning rate in obvious fashion. If for example a singly perforated cylindrical stick or grain is entirely covered externally, the internal surface, continually increasing, yields progressive instead of neutral burning.

We have discovered that desirable burning properties can be incorporated by the use of slots cut into the body of the propellant grain. It is therefore an object of this invention to produce a new and improved slotted granulation for powder. More specifically, we have found that a neutral propellant can be formed from an externally covered perforated cylindrical grain by the use of radial slots cut in one end of the grain. It is consequently another object of the invention to use radial slots to produce a neutral grain from one restrictively coated externally. Other objects will appear hereinafter.

In the drawings:

FIG. 1 shows a top view of a grain of powder with six radial slots forming equally spaced sectors;

FIG. 2 represents a vertical section of the grain taken along the line 2—2 of FIG. 1;

FIG. 3 shows a top view of a grain with five radial slots forming unequal sectors;

FIG. 4 shows the variance of the surface of an uncompensated single perforated grain restricted on the sides and one end, the degressive effect of the end area becoming less with increase in grain length;

FIG. 5 shows the rate at which the surfaces of various sectors will decrease;

FIG. 6 shows the burning of one sector, B representing the central angle;

FIG. 7 shows the burning of a grain with five equal sectors;

FIG. 8 shows the burning of a grain with unequal sectors;

FIG. 9 shows the geometric relationship of burning surface to distance burned;

FIG. 10 shows U-shaped burning at the bottom of a perforation.

These figures show a cylindrical grain stick or rod of powder 1 with a longitudinal perforation 2 extending throughout its length and a coating 3 restricting burning externally except along the top surface. In one embodiment of the invention equal sectors 4 are formed by slots 10 cut into the exposed top and extending about one fourth of the distance between the ends of the grain. In another embodiment unequal sectors 5—9 are formed by the slots 10 extending about one-fourth the length of the grain as in the previous case.

Upon ignition the stick burns on top, from the perforation out and along the slots. The central area of the perforation constantly increases but the area of the sectors defined by the slots continually decreases. The rates of change in these areas can be made to cancel each other and thus produce a neutral propellant, the regressiveness of the slots compensating for the progressiveness of the perforations. As the length of the grain increases the degressive effect of the circular end area becomes less.

The initial surface is increased by cutting the slots in the end of the grain, the number and depth of the slots depending on the amount of surface necessary. As noted above, the surface exposed by the slots becomes less while the burning progresses. The rate at which the surface of the slots will decrease depends upon the central angles of the sectors, that is, the angle between slots.

If the slots are cut at equal angles as in FIG. 1 the compensating effect will disappear midway through burning, FIG. 7. To avoid this usually undesirable result, the sectors should be designed as in FIG. 3 with different central angles and will be consumed, one by one, over a predetermined interval of time.

Several advantages are offered by the geometry of the present invention. For example, the pressure-time record is more nearly neutral with this grain than it is with the competitive star-centered or cone and cylinder types. Strict neutrality is especially desirable where constant thrust propellants are necessary as in jet assisted take off units.

Furthermore, the instant granulation offers a long burning distance. The burning distance is the complete length of web of the perforated part. For a grain with an 8.5 inch outside diameter and a 0.5 inch internal diameter the burning distance is 4 inches. The longer the burning distance the longer the period of gas evolution and hence of thrust.

Granulation of the slotted type is extremely simple to manufacture. The desired shape can be made by placing a non-adhesive core in a restrictive container and filling the volume with cast propellant. Put together in this manner, the unit possesses a very high loading density. Ninety-eight percent of the volume of the container can be filled with the propellant and its restrictive coating, ninety percent by the propellant itself.

Advantages in economy of materials and design of the container are also found. Even in the rosette grain some small slivers of powder remain unburned although the Walsh improvement reduces such losses by fifty percent over the usual perforated grain. Use of the slots, however, eliminates unburned materials. Design of the container is simplified because of the ease of gas elimination where effectively a single perforation is used. No difficulty is consequently encountered in either porting

or trapping arrangements. Gases produced by slow decomposition also escape without difficulty since the diffusion distance for such gases is never very great.

The size and depth of the slots and sector angles may be calculated from the known characteristics of the propellant used. As an illustration, the design of a neutral outward burning charge for an eight second jet assisted take-off unit will be given.

For the purposes of calculation it will be assumed that a propellant with the following properties is available:

Temp. ° F.	Pres., p.s.i.	Rate, in./sec.
−40	875	0.375
70	1,000	0.46
130	1,200	0.50

Pressure index of rate, "n"_____ 0.50.
Density, "d"_____ 0.056 lb./in^3.

Temperature coefficient, $\left[\frac{d \ln P}{dT}\right]_K$ 0.006/deg. C.

Specific impulse, I_____ 193 lb. sec./lb.

The operating limits of the motor are to be:

Pressure_____ 1200 p.s.i.
Temperature_____ −40 to +130° F.
Thrust, F_____ Approximately 1000 lbs.
Burning time_____ 8 second minimum.
Maximum diameter of propellant_____ 9.0 in.

The minimum burning distance of the grain, the web, is:

8 sec.×0.5 in./sec.=4 in.

Allowing 0.5 inch for a restrictive coating, the external diameter is 8.5 inches. A perforation with a diameter of 0.5 inch leaves a web of 4.0 inches.

If a minimum thrust of 900 lbs. at −40° F. is chosen, the rate of discharge is:

$$m=\frac{F}{I}=\frac{900}{193}=4.66 \text{ lb./sec.}$$

and the burning time

$$t_b=\frac{4 \text{ in.}}{0.375 \text{ in./sec.}}=10.67 \text{ sec.}$$

The total weight of propellant required is therefore:

$$m\times t_b=10.67\times 4.66=49.9 \text{ lb. (50 lb.)}$$

The surface required is:

$$S=\frac{m}{d}\times \text{rate}=\frac{4.66}{0.056\times 0.375}=222 \text{ in}^2$$

At the upper temperature limit this dimension will provide a thrust of

$$F=mI=\frac{50.0}{8}\times 193=1200 \text{ lb.}$$

The powder volume is

$$\frac{50}{0.056}=893 \text{ cu. in.}$$

The length of the grain will be approximately:

$$l=\frac{893}{\pi/4[(8.5)^2-(0.5)^2]}=15.8 \text{ in.}$$

The length of the grain at the final instant of burning will be

$$l=\frac{222}{8.5\pi}=8.33 \text{ in.}$$

The length of grain which will be consumed by end burning will be equal to the web, 4 inches. Thus the depth of the slots must be:

$$15.80-8.33-4.0=3.47 \text{ in.}$$

Arbitrarily the width of the slots is set as 3/16 inch. This width will provide more than enough port area.

To simplify calculations, a hypothetical grain shape

will be assumed which will be consumed exactly as the actual grain with the regressing sectors. This hypothetical grain will have the following dimensions:

O. D_____ 8.5 in.
I. D_____ 0.500−2(3/32)=0.312 in.
Length_____ 15.80−3/32=15.89 in.
Web_____ 4.09 in.
Width of slot_____ 0.00 in.

After all surfaces of the hypothetical grain have regressed 3/32 inch, the hypothetical grain will have the same shape as the actual grain.

At the beginning of burning the slots must provide

$$222-\pi/4[(8.5)^2-(0.312)^2]-0.312\times 15.8=150 \text{ sq. in.}$$

Each slot provides $2\times 4.09\times 3.50=28.6$ sq. in. and

$$\frac{150}{28.6}=5.24$$

slots are required. Of course five slots will be cut, each exposing 30 sq. in. the depth being

$$\frac{30}{4.09\times 2}=3.67 \text{ in.}$$

The overall length of the hypothetical grain will be $3.67+8.33+4.09=16.09$ in.

The dimensions now established are:

	Hypothetical	Actual
O.D., in	8.5	8.5
I.D., in	0.312	0.5
Length, in	16.09	16.00
Number of slots	5.0	5.0
Depth of slots, in	3.67	3.67

For any sector the distance of burning is

$$b=R \sin \frac{B}{2}=\sin \alpha$$

(FIG. 9), R representing the radius of the grain.

It can be seen from FIG. 7 that the largest sector should be consumed only after 3.5 inches of burning. Consequently

$$\gamma=2 \sin^{-1} \frac{3.50}{4.25}=108°$$

Here γ is the angle of sector 7 in FIG. 3.

The remaining angles are chosen so that they are spread quite uniformly and add up to 360°:

Sector—	Angle, °
6	25
5	50
9	75
8	100
7	110
	360

During burning the side surface of a sector will decrease as the parallel layers meet each other at the point. The length "c" of one side of a sector after a distance "p" has been burned is

$$c=\sqrt{R^2-p^2}-p \text{ ctn } \alpha \text{ (FIG. 9)}$$

Because of the perforation $c=4.09$ in. R=radius of grain/2.

The total surface exposed on the faces of the sectors at any time is: $S_s=2\times$(depth of slot)$\times \Sigma c$ where

$$\Sigma c=\sqrt{R^2-p^2}-p \text{ ctn } 12.50°$$
$$+\sqrt{R^2-p^2}-p \text{ ctn } 25° \ldots +\sqrt{R^2-p^2}-p \text{ ctn } 55°$$

It has been assumed that the bottoms of the slots burn with square corners. Actually the corners burn U-shaped, as shown in FIG. 10. The decrease in surface due to this effect is

$$-\Delta S=2[2p-1/4\times 2\pi p]\Sigma c=0.86p\Sigma c$$

Symbols here are as shown in FIG. 10.

The slots in the actual grain will be cut with rectangular

bottoms for which

$$-\Delta S=0.86(p-0.09)\Sigma c$$

deeper slots is tabulated in Table 2 and shown graphically in FIG. 8.

TABLE 2

Burning Surface of Slotted Grain

P	ΣC, in.²	Surface of sectors, in.²	End and lateral surface in.²	U-shape correction, in.²	Correction for "Runt" sector in.²	Total surface, in.²
0	20.45	170.5	67.7	− 0	−14.4	221.8
.25	18.74	156.2	87.1	− 4.0	−13.2	226.1
.50	16.36	136.5	104.4	7.0	− 9.4	224.5
.75	14.50	121.0	120.4	− 9.1	− 5.5	226.8
1.00	12.21	102.0	135.4	−10.5	− 2.5	224.4
1.25	10.08	84.0	148.5	−10.9	----------	221.6
1.50	8.50	70.9	161.8	−11.0	----------	221.7
1.75	6.87	57.2	172.2	−10.3	----------	219.6
2.00	5.69	47.4	183.0	− 9.8	----------	220.6
2.25	4.58	38.2	192.3	− 8.9	----------	221.6
2.50	3.39	28.2	200.3	− 7.3	----------	221.2
2.75	2.24	18.7	206.0	− 5.3	----------	219.4
3.00	1.15	9.6	212.2	− 3.0	----------	218.8
3.25	0.45	3.8	217.1	− 1.3	----------	219.6
3.50	0	----------	219.5	0	----------	219.5
3.75	-----	----------	221.6	----------	----------	221.6
4.00	-----	----------	222.1	----------	----------	222.1
4.09	-----	----------	222.0	----------	----------	222.0

Table I is the tabulation of all the surface at equal intervals of burning distance, using the dimensions calculated. From Table I it can be seen that the calculated shape will result in fairly smooth burning. But at $p=1.25$ inches the surface is 10.4 square inches, 5% below the desired 222 square inches. To supply the extra surface the slots could be cut

$$\frac{10.4}{10.08\times 2}=0.51$$

in deeper (by increasing total length). However, at $p=0$ the increase in surface would be 22 square inches and at $p=0.25$, 19.1 square inches. This overbalance at the beginning can be corrected by making the first sector a runt, either by cutting it an inch or two lower than the rest or by recessing the point from the center. Thus the dimensions of the grain are:

	Hypothetical	Actual
O.D., in	8.5	8.5
I.D., in	0.312	0.5
Web, in	4.09	4.0
Length, in	16.59	16.50
Number of slots	5	5
Depth of slots, ins	4.17	4.17

TABLE 1

[Surface of hypothetical grain 8.5 x .312 x 16.0", 5 slots 0.00 inches wide by 3.67 inches deep cut at 25°, 50°, 75°, 100°, 110°]

Distance burned, in.	Annular end surface, in.²	Surface of perforation, in.²	c, in.²	Surface of slots, in.²	Correction for U-shape, in.²	Total surface, in.²
0	56.5	11.2	20.45	151.0	0	218.7
.25	56.1	31.0	18.74	137.4	4.0	220.5
.50	55.2	49.2	16.36	120.0	7.0	217.4
.75	54.0	66.4	14.50	106.3	9.1	217.6
1.00	52.4	83.0	12.21	89.6	10.5	214.5
1.25	50.4	98.1	10.08	74.9	10.9	211.6
1.50	48.0	113.8	8.50	62.4	11.0	213.2
1.75	45.2	127.5	6.87	50.5	10.3	213.2
2.00	42.0	141.0	5.69	41.7	9.8	214.9
2.25	38.3	154.0	4.58	33.6	8.9	217.0
2.50	34.3	166.0	3.39	24.9	7.3	217.9
2.75	30.0	176.0	2.24	16.4	5.3	217.1
3.00	25.2	187.0	1.15	8.45	3.0	217.6
3.25	20.1	197.0	0.45	3.3	1.25	219.2
3.50	14.5	205.0	0.00	0	0	219.5
3.75	8.6	213.0	-----	----------	----------	221.6
4.00	2.1	220.0	-----	----------	----------	222.1
4.09	0	222.0	-----	----------	----------	222.0

The angles of the sectors are to be 25°, 50°, 75°, 100°, and 110°. A 2.0 inch layer is to be cut from the top of the 25° sector. The surface of the grain with the

The variation in surface during burning is only

$$\frac{226.8-219.1}{223}\times 100=3.5\%$$

Scale model grains have been fired. Slots were milled in 2.75 x 0.75 x 5.75 in. composite propellant grains. The variation in surface during burning was expected to be higher than calculated, due to rough machining, but amounted to only 13%.

What we claim is:

1. An outward burning neutral granulation for cast propellants consisting of a solid cylindrical grain having top and bottom surfaces, a side wall and a length greater than the radius of said grain, said grain also having a longitudinal axis of symmetry and an axial perforation coextensive with said depth, a restrictive coating covering said side wall and said bottom surface, there being a plurality of angularly related slots coextending radially outwardly between said perforation and the outer curved surface of said grain, said slots having an axial dimension smaller than said length and equal approximately to said radius, said slots opening through said top surface.

2. The propellant of claim 1, there being six slots formed in said grain, said slots being equally angularly related.

3. The propellant of claim 1, there being five slots formed in said grain, said slots being unequally angularly related.

4. The propellant of claim 1, there being five unequally angularly related slots formed in said slots having a progressive angular relation of 25 degrees, 50 degrees, 75 degrees, 100 degrees and 110 degrees respectively.

5. An outward burning granulation for a jet assisted take-off unit having constant evolution of gas pressure and consisting of a propellent grain of cylindrical configuration having a predetermined outer diameter, there being an axial perforation coextensive with the length of said grain, said grain having a length greater than the web defined by the radial distance between the outer surface of said grain and the periphery of said perforation, a restrictive coating covering one end of said grain and the curved surface thereof, there being a plurality of slots opening through the uncoated end of said grain and co-extending radially between said perforation and the outer curved surface of said grain, said slots having a depth approximately equal to said web.

6. The propellant of claim 5, there being a total of six slots formed in said grain, said slots being equally angularly related.

7. The propellant of claim 5, there being a total of five slots, said slots being unequally angularly related.

8. The propellant of claim 5, there being a total of five slots, said slots being unequally angularly related, said slots having a progressive angular relation of 25 degrees, 50 degrees, 75 degrees, 100 degrees and 110 degrees respectively.

9. An outward burning granulation for a jet assisted take-off unit having constant evolution of gas and consisting of a propellant grain of cylindrical configuration having an external diameter of 8.5 inches, there being an axial perforation coextensive with the length of said grain having a diameter of 0.5 inch, said grain having a length of 16.5 inches, a restrictive coating covering the curved surface of said grain and one end, there being a plurality of unequally angularly related slots co-extending radially between said perforation and the external surface of said grain and opening through the uncoated end thereof,

said slots having a depth of 4.1 inches, said slots also having a progressive angular relation of 25 degrees, 50 degrees, 75 degrees, 100 degrees and 110 degrees respectively.

10. An outward burning granulation for a jet assisted take-off unit having constant evolution of gas pressure consisting of, a cylindrical propellant having a length approximately twice the outer diameter of said grain, there being an axial perforation coextensive with the length of said grain, the radial burning distance between the outer surface of said grain and said perforation defining the web of said grain, a restrictive coating covering the curved surface of said grain and one end, there being a plurality of radial slots co-extending between said perforation and the outer surface of said grain and opening through the uncoated end thereof, said slots having a depth approximately equal to said web.

11. The grain of claim 10, said slots being equally angularly related.

12. The grain of claim 10, there being five unequally angularly related slots.

13. The grain of claim 10, there being five unequally angularly related slots, said slots having a progressive angular relation of 25 degrees, 50 degrees, 75 degrees, 100 degrees, and 110 degrees.

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