The Modeling and Simulation of Chaff Release at High Speed

Jijin Tong1,* Zhong Liu1 and Liqin Xu2
1Naval University of Engineering, Wuhan, Hubei Province, China
2Xi’an University of Posts &Telecommunications, Xi’an, Shangxi Province, China
*Corresponding author email: tongjj7802@sina.com

Abstract. Commonly, chaff cartridge release the chaff based on detonating the dynamite or blasting form projectile. In order to improve the scatter effect of chaff, a novel technique of chaff release is proposed, which is be carried by a given carrier revolving around an axis at high speed. And the model of chaff motion in the phase of dispersing rapidly is established on the basis of the analysing the influence of resistance, gravity and viscous force. Simulation instance show that the method based on revolving carrier is efficacious, and some useful revelation can be elicited from the simulation. The research in this paper has great significance for the research and engineering implementation of gun launched chaff jamming projectile.

1. Introduction
Chaff jamming technology is an important part of electronic countermeasures, which has developed over half a century and has undergone various war verification, since the second world war. Although the radar technique develop highly nowadays, jam technology of chaff clouds also is an effective means in the anti-radar field[1]. During the process of counterworking radar, especially the missile’ s terminal guidance radar, by chaff clouds, the kinematics characteristic of chaff release is very important, which demand the chaff disperse quickly, and arrive at a higher Radar cross section in a short time. At present the commonly means of chaff releasing is no more than the following several ways: one-time detonating type to scatters chaff, interference rocket type to achieve chaff releasing, chaff be dispersed by Jet device, etc. And no matter which way to scatter chaff, the key problems is try to enhance the delivery speed of chaff, to increase the flow Reynolds number, finally to impel the chaff dispersing quickly.

A novel means of Chaff Release is Put forward, which is based on a given carrier revolving around central axis at high speed, and scatters chaff by the centrifugal force when the carrier rotating at high-speed. And the model of chaff motion in the phase of dispersing rapidly is established on the basis of the analyzing the influence of resistance, gravity and viscous force. Simulation instance show that the method based on revolving carrier is efficacious, and the method had be verified by the further field test, it has important guiding significance to the research and development of new chaff bomb.

2. The New Method of Chaff Scatters Based on the High Speed Rotating Carrier
When chaff is used to interfere with radar, it is the on of the key indicators that the chaff disperse quickly, arrive at a higher Radar Cross Section in a short time, and achieve corresponding role. For example, with the rapid development of radar technology, the time of chaff diffuse is requested to higher requirements, and the dispersion time requirements of millimeter-wave chaff shells have reachd 0.1-0.2 seconds[2]. The traditional Chaff bomb is commonly scatter the chaff by one-time detonating type methods, trying to enhance the delivery speed of chaff and to increase the flow Reynolds number.
The specific methods may be as follow: the plane may launch forward the chaff rockets, or can use detonate type chaff device; Ship can use chaff interference rocket, and equipped with suitable explosive for chaff’s rapid diffuse; in ground we can use mortar or other artillery launch chaff bomb. All the methods are applied to add kinetic energy to the chaff, which can increase the linear speed of the chaff and realize chaff scatter quickly. The novel method of chaff scattering quickly is put forward in the paper as follows: using the high speed rotating cylinder as the carrier, chaff beam is loaded in the hollow of the cylinder, as shown in figure 2 and figure 3. The cylinder revolving around longitudinal-central-axis at high speed, and the chaff will be push out of cylinder quickly. And it is clear that the more higher of the Cylinder’s angular velocity can produce the more greater of chaff centrifugal force. When the chaff have no enveloping external force, the chaff scatter around quickly because of the effect of centrifugal force, as shown in figure 4.

3. Kinematics Characteristics Analysis of Chaff in the Air
When we try to analysis the process of chaff release, we should analysis the force effected on the single chaff in the air, deduce and set up the motion equation of single chaff in the atmosphere, firstly. Chaff is a long cylinder, which has two Characteristic scale: the length of chaff “l” and the cross section diameter of chaff “d”, commonly \( d \leq l \).

According to the theory of fluid mechanics\(^3\), the force of chaff in air by resistance is as:

\[
W = \rho l d v^2 f(\alpha, R)
\]  

(1)

Here: \( \rho \) - is air density, 
\( l \) - is the length of the chaff, 
\( d \) - is the diameter of the chaff,
v - is the movement speed of chaff,
$\alpha$ - is $v$ the angle between the velocity vector “v” of chaff and chaff’s main characteristic measure (length “l”),
$f(\alpha, R)$ - is dimensionless value function of “$\alpha$” and ”$R$”, which is normally be obtain through the experiment,
$R$ - is Reynold number. $R = \rho lv / \mu$,
$\mu$ - is the viscosity coefficient of fluid.
The theoretical research and experimental data show that the role of fluid viscosity will decrease when the object has large Reynolds number. The chaff has the same angular velocity as its carrier before being released from the given carrier revolving around an axis at high speed, and will have high line speed along the tangent direction when be dispersed from the carrier. The chaff have a large Reynolds number, the viscous force also can be ignored. So the force of chaff can be simplified as follow:

$$F = W = pldv^2 f(\alpha)$$  \hspace{1cm} (2)

When the direction of “v” is stated, the chaff roll in the air discretionarily, if we suppose that the tropism of chaff’s movement is symmetrical, also that the angle of tropism submit to uniform distribution in the three-dimensional space of $4\pi$, so the expression of $f(\alpha)$ can be received form judging by a process of logic, basis of literature [4], $f(\alpha)$ can be expressed as follow:

$$f(\alpha) = M \sin \alpha = (\rho_o dg / \rho v_o^2) \sin \alpha$$  \hspace{1cm} (3)

Combine expressions (2) and (3), we can get

$$F = W = pldv^2 f(\alpha)$$
$$= pldv^2 (\rho_o dg / \rho v_o^2) \sin \alpha$$  \hspace{1cm} (4)

4. The Diffusion Model of Chaff Based on the High Rotating Carrier
Now, we can establish the diffusion method of chaff based on the high-speed rotating carrier. The chaff rotates in high speed with the cylinder, it has the same angular velocity with cylinder before the chaff been pushed out of the cylinder completely, and due to the effect of centrifugal force it scattering out quickly along the tangent quickly when the chaff be scatter out of the cylinder completely.
For the sake of analyzing expediently, the rectangular coordinate system of cylinder is be established as follow: with the cylinder rotation axis as origin, the horizontal direction for X axis, vertical direction for the Y axis, as shown in figure 5. Now, if we choose a chaff randomly, we can establish the kinematics model of the chaff’s diffuse based on the analysis of the chaff’s force and movement.

![Figure 5. Sketch map of Chaff locomotor trend in different quadrant.](image)

Firstly, we should ascertain the initial position of the chaff. Suppose that one of the chaff bundled and loaded in the cylinder which intersects the plane $XOY$ vertically through dot $M$, the distance away from the origin is $D$, the angle between the X axis is $\alpha$, then we get the initial position of the chaff before it scatter away as follow:
\[
\begin{align*}
X' &= \frac{D}{2} \cos \alpha \\
Y' &= \frac{D}{2} \sin \alpha
\end{align*}
\] \quad (\alpha \in (0, 2\pi)) \tag{5}

Secondly, the moving trend of the chaff should be analysis after it be push out of the cylinder. Suppose that one of the chaff is in the first quadrant of the rectangular coordinate system, as shown in figure 5, the rotary rate is \( \omega \), and in the period of time \( t \), the linear distance of the chaff dispersed away from the initial position is \( S \), then we can get the chaff’s projection position in the plane \( XOY \). Specific methods are as follows:

\[
\begin{align*}
X &= X' + S_x = D \cdot \cos \alpha + S \sin \alpha \\
Y &= Y' + S_y = D \cdot \sin \alpha + S \cos \alpha
\end{align*}
\] \quad (6)

Now, the sixty-four-dollar question is to calculate the distance \( S \). Supposed that the air is placid, in other words there is not the effect of onflow and wind in the air, we can get the follow expression from formula (4):

\[
W = \rho l d\alpha f(\alpha) = m_f \frac{dv}{dt}
\] \quad (7)

Solving which, we can get:

\[
v(t) = \frac{m_f v_0}{m_f + \rho l d\alpha f(\alpha)t}
\] \quad (8)

Here: \( m_f \) - is the weight of chaff,
\( v_0 \) - is the initially rectilineal speed of chaff, equal to \( 2\pi D \omega \)

the rectilineal distance is:

\[
S(t) = \frac{m_f}{\rho l d\alpha f(\alpha)} \ln[1 + \frac{\rho l d\alpha f(\alpha)}{m_f} t]
\] \quad (9)

Combine expressions (9) and (6), we can get the chaff’s position in a given time \( t \), Specific expression is as follows:

\[
\begin{align*}
X &= D \cos \alpha + \frac{m_f}{\rho l d\alpha f(\alpha)} \ln[1 + \frac{\rho l d\alpha f(\alpha)}{m_f} t] \sin \alpha \\
Y &= D \sin \alpha + \frac{m_f}{\rho l d\alpha f(\alpha)} \ln[1 + \frac{\rho l d\alpha f(\alpha)}{m_f} t] \cos \alpha
\end{align*}
\] \quad (10)

In like manner, we can also get the chaff’s position when the chaff is in the second, third and fourth quadrant of the rectangular coordinate system. And through the above equations we can calculation the motion of any given chaff, and also can get the real-time overall diffusion state if all the information of every chaff is clear.

5. The Simulation Analysis

According to the above analysis, the authors establish the hypothesis: the cylinder with chaff is placed in a horizontal position and rotate around with the axis, and the value of the angular velocity can be adjusted; the type of the chaff can be replaced; the inside packing arrangement can meet the uniform distribution, no matter with position or with angle, and independently.
Then, we can simulate according to the chaff diffusion model. Here we hypothesis that the cylinder inner diameter is 0.1 meters, the angular velocity has 4 grade: 100 r/sec, 200 r/sec, 300 r/sec and 400 r/sec respectively, and with 0.01 seconds for the simulation time step. Through the simulation by MATLAB, we can achieve the situation simulation diagram of the chaff spread in any time. Figure 6 show the chaff diffusion simulation results within 0.1 second with the fact that the cylinder inner diameter is 0.1 meters, the angular velocity is 400 r/sec, chaff length 14 mm, the number of chaff is 1000. Then the simulation results show: the largest length of chaff cloud is about 13.1 m. The simulation result tally with the experimental result in literature [5].

![Figure 6](image_url)

**Figure 6.** Diagram of Chaff 'Kinematics characteristic in same rotational speed changing along with temps.

In order to further analysis of the chaff scatters performance, we analysis the simulation results by the way of contrasting different angular velocity with the time, and we can get the contrast diagram of two lengths chaff in different angular velocity with the time, as shown in figure 7 shows.

![Figure 7](image_url)

**Figure 7.** Contrast diagram of Chaff 'Kinematics characteristic in Different rotational speed changing along with temps.

From the simulation results we can get that:
1. In the different four grades of rotational speed, the short chaff’ diffusion radius is larger than the long chaff’ diffusion radius.
2. No matter short chaff or long chaff, along with the increase of rotation speed, the diffusion speed enhance significantly. And the chaff can diffuse completely in 0.1 seconds, when the angular velocity arrive at more than 400 r/sec.
3. The final diffusion radius of chaff with the same length changes little, when the chaff is scattered in different angular velocity. For example, as for the short chaff, when the angular velocity increases from 200 r/sec to 400 r/sec, the rotating speed is increased to 2 times, but the scatters radius increased only less than 0.4 m.
Therefore, through the high speed rotating scatters way, short chaff scatters diffusion radius is larger than the long chaff. And if we try to realize that the chaff diffuses quickly in 0.2 seconds quickly, rotation speed should be more than 200 r/sec.

6. The Validation Test
In order to verify the effectiveness of the proposed method, a hollow cylinder is designed, in which there is a piston type push-plate mechanism, the chaff is loaded along the axis of the cylinder, and the bottom end is sealed with tin foil to prevent the chaff from falling out, the upper end of the cylinder is rigidly connected with the high-speed turntable through a connecting rod. The piston type push-plate mechanism is started to remove the chaff when the turntable speed is stable during the experiment. The high-speed camera was used to record during the whole process, and after the experiment we observe the distribution of chaff on the ground. The experimental results show that:

(1) After the chaff is pushed out of the cylinder, the chaff can disperse rapidly through the rotation of the high-speed turntable. We can see the that the area of the chaff formed on the ground is larger when the rotation speed of the turntable is higher; but when the rotation speed increases to 500 rpm, the area of the chaff formed is almost the same.

(2) The dispersing effect of short chaff is larger and better than that of long chaff, and the long chaff is easier to form winding.

7. Conclusion
The naval gun has the characteristics of high firing rate, long range, fast calculation speed, large load and convenient loading, and if the chaff can be carried and dispersed by the cannonball, there maybe could be a big change. And the exterior ballistic rotation speed of naval gun’s cannonball is generally more than 200 rpm. For example, the muzzle rotation speed of a 127mm caliber naval gun is more than 300 rpm, and the minimum rotation speed of the whole exterior ballistics is also above 220 rpm. Therefore, this method can be applied to the design of chaff jamming projectile launched by naval gun. The research in this paper has great significance for the research and engineering implementation of gun launched chaff jamming projectile.

References
[1] Jin Chen. Principles of Radar chaff jamming[M]. BeiJing: publishing company of national defence and industry,2007.

[2] Tang Yuyan, Du Jiacong. The Fast Spread of Millimeter Wave Foils from a Chaff Despenser and Their Time-frequency Domain Characteristics[J]. Journal of GuiLin Institute of Electronic Technology, 1999,19(4):2-5.

[3] Li Jin-liang, Li Yong-zhen. Chaff jamming diffusion model in low orbit space[J]. Journal of astronautsapail,2010,4:1237-1243.

[4] Chen Jing. The Study of fast Spread of Millimeter Wave Foils from a Chaff Despenser[J]. Electronic Information Warfare Technology,1992,(6): 41-46.

[5] Han Chao, Zhao Guozhi, Yang Zhiqiang. Study on the Kinematics Characteristic of Chaff Release[J]. Initiators & Pyrotechnics, 2005,(1):6-8.

[6] Sun Xinli, Cai Xinghui, Wang Shaolong. Projectile test from a bomb dispenser[J]. Acta Armamentarii, 2002,23(2): 258-260.

[7] TAO Ruyi, WANG Hao, HUANG Be The Model and Simulation of Aerial Dispersing on Piston Dispersal Mechanism of Cluster Munition[J]. Acta Armamentarii, 2009,30(3):282-284.

[8] A. Shapio, H.(U.S), Form and flow[M]. Beijing: Science Press,1979.

[9] Wang Hangyu, Wang Shijie, et al. Principle of Shipborne fire control[M]. Beijing: National defence industry Press,2006.