Estes Industries Technical Report TR-2

MULTI-STAGING

by Vernon Estes

These reports are published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colorado.

Multi-staging is one of the most prominent characteristics of modern rocketry. This technique is used with solid propellant rockets and liquid propellant rockets, in rockets less than a foot tall and in rockets which tower to over one hundred feet. Multi-stage rockets are used to send up payloads from ants to humans to 500 feet, into orbit, and on to other planets.

The performance necessary for high orbits, moon shots and interplanetary probes is provided by multi-stage rockets. The principle advantage of multi-staging is the elimination of unnecessary weight in the later portions of the rocket's flight. For example, compare two rockets weighing 1500 pounds at takeoff, one a single stage missile and the other a two stage rocket. The single stage rocket holds 1000 pounds of fuel inside a 500 pound body while the two stage rocket consists of two 250 pound bodies, each carrying 500 pounds of fuel. When half the fuel in the single stage rocket is used there is still another 1000 pounds for the remaining half of the fuel to carry. On the other hand, when half the total fuel load of the two stage rocket is used the stages separate, leaving 250 pounds of dead weight behind, with only 750 pounds for the remaining half of the fuel to move. This weight saving is even greater at burnout when the single stage rocket weighs 500 pounds and the multi-stage rocket only 250.

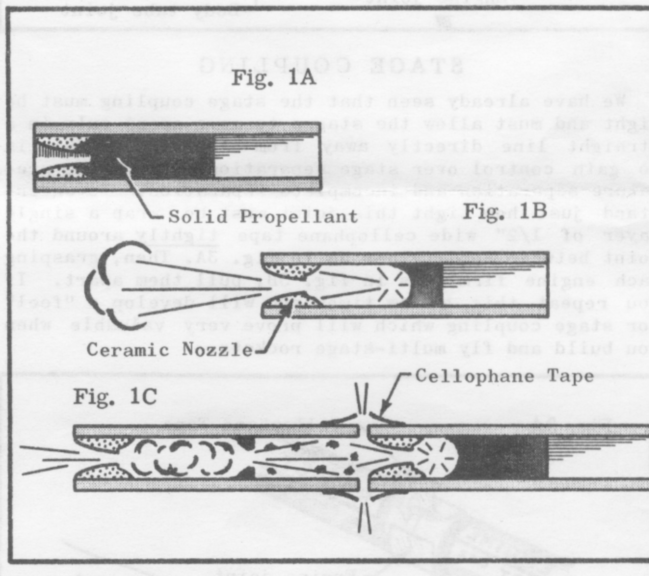
The principles of model rocketry and professional rocketry are identical although the model rocketeer uses somewhat different operating methods than the professional. The young rocketeer who masters the principles of multi-staging is gaining knowledge which he will find useful in his future career.

IGNITION

The lower or first stage of a multi-stage rocket is always ignited by standard electrical means. For further details, refer to the instruction sheet which is included with all rocket engines. The second stage ignition is accomplished automatically upon burnout of the first stage. As you will notice in figure 1A, the first stage engine has no delay or ejection charge. This is to assure instant ignition of the following stage upon burnout.

In figure 1B the propellant has been partially burned leaving a relatively large combustion chamber. As the propellant continues to burn, the remaining wall of propellant becomes thinner and thinner until it is too thin to withstand the high pressure inside the combustion chamber. At this point the remaining propellant wall ruptures, allowing the high pressure inside the combustion chamber to exhaust forward toward the nozzle of the next stage, carrying hot gases and small pieces of burning propellant into the nozzle of the second stage engine. This action is illustrated in figure 1C.

For this system to work, the rocket must be designed and built to make the best use of the operation of the engines. If the upper stage engine is simply placed



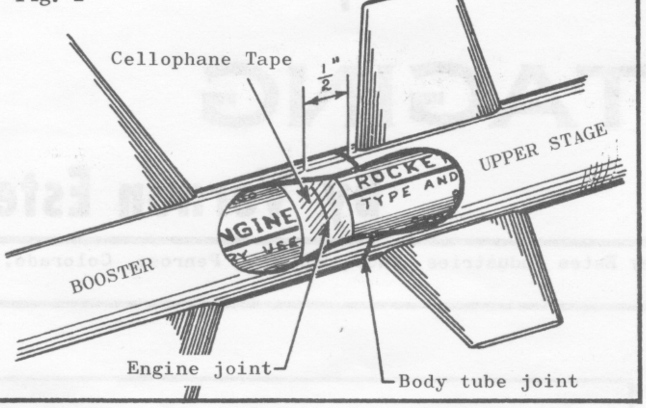
ahead of the booster engine so that the two can separate easily, ignition reliability may fall as low as 40 percent, depending on the type of booster used (except when a Series II engine is used in the upper stage, in which case reliability will be about 80 percent). This unreliability in ignition is the result of several causes. First, when the forward propellant wall of the booster burns through, high pressure is built up in the area between engines. This pressure will force the stages apart. Second, the nozzle of the upper stage engine is quite small (.009 square inches in a Series I engine), making a difficult target for the hot gases and burning particles. Also, the nozzle of the upper stage will cool gases slightly as they enter it.

These problems in multi-stage ignition led to an extensive research program at Estes Industries. Revisions in engine design, gimmicks such as pressure relief vents, etc., were tried, but none proved satisfactory. What was needed was a method of controlling stage separation so that the hot ignition gases would have a proper chance to act on the upper stage engine before the upper and lower stages parted company.

After data on several hundred test firings had been collected, the problem was reanalysed to find the factors which contributed most to reliability. There were two: An extremely tight joint between stages and a coupling which forced the two stages to move apart in a completely straight line.

The simplest, most reliable method of joining stages tightly was immediately considered--tape. By wrapping one layer of cellophane tape around the joint between engines and then recessing this joint 1/2" rearward in the booster body tube, as in fig. 2, reliability suddenly jumped to almost 100%. Thus it was discovered that the coupling system played the most important part in multi-stage ignition reliability.

Fig. 2



STAGE COUPLING

We have already seen that the stage coupling must be tight and must allow the stages to move apart only in a straight line directly away from each other. This is to gain control over stage separation, preventing premature separation and incomplete separation. To understand just how tight this joint must be, wrap a single layer of 1/2" wide cellophane tape tightly around the joint between two engines as in fig. 3A. Then, grasping each engine firmly as in fig. 3B, pull them apart. If you repeat this a few times you will develop a "feel" for stage coupling which will prove very valuable when you build and fly multi-stage rockets.

Fig. 3A

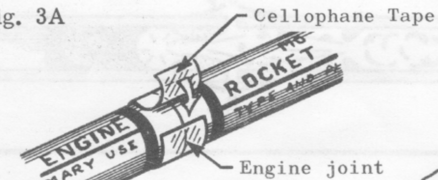
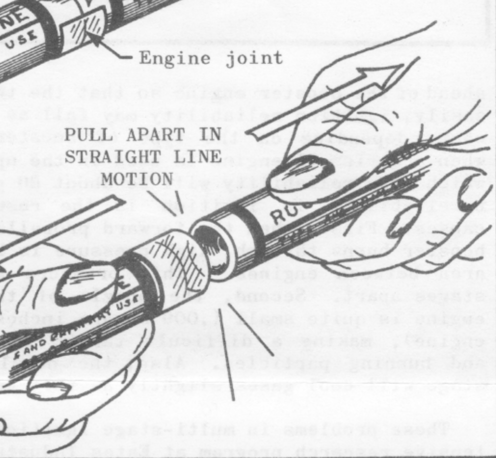


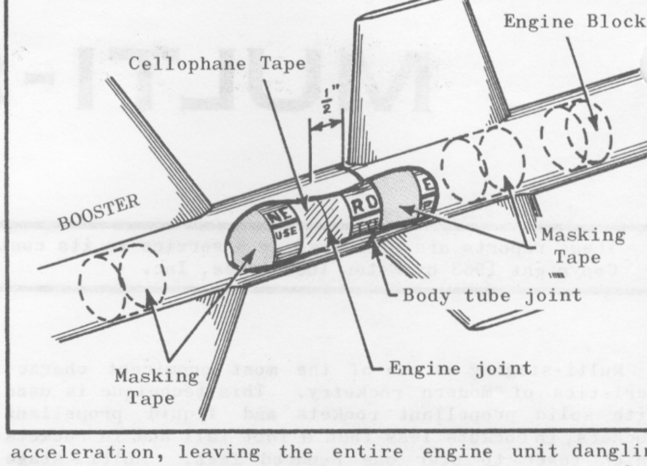
Fig. 3B



The proper coupling system to use in a rocket will depend on the size of the body tube. The coupling system for rockets using tubes of approximately 3/4" diameter (BT-20, BT-30, and BT-40) is shown in fig. 4. With this system the upper stage engine must project at least 1/2" rearward into the booster body tube to provide straight line separation. The engines are taped together before being inserted into the rocket. Check carefully before and after taping to be sure the engines are in their proper positions (nozzle of upper stage engine against top end of booster engine). Failure to check carefully can be highly embarassing as well as damaging to the rocket.

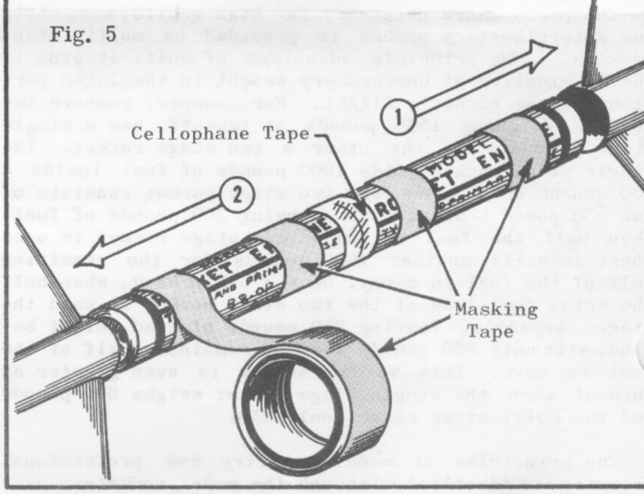
When the engines are taped together they can be inserted into the rocket. Wrap masking tape around the upper stage engine at the front and near the rear as in fig. 5 to give it a tight fit in the body and push it into place. Then wrap the booster engine and push the booster into position. Failure to get the upper stage engine in place tightly enough will result in the recovery system misfunctioning, while failure to get the booster on tightly can result in its dropping off under

Fig. 4



acceleration, leaving the entire engine unit dangling from the upper stage while the rocket loops around in the air.

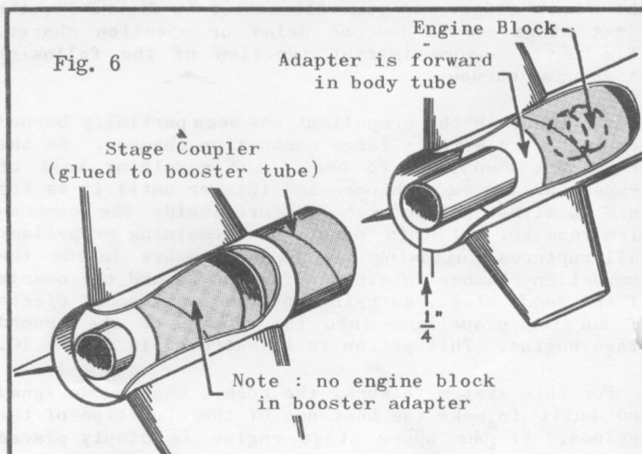
Fig. 5



The procedures used for two stage rockets should also be used on rockets with more stages. It is important, however, to get considerable experience with two stage rockets before attempting to design a 3 or 4 stage model.

Rockets using large diameter tubes (BT-50 and BT-60) require somewhat different methods, but the same principles of tight coupling and straight line separation must be followed. The recommended coupling method for larger diameter tubes is illustrated in fig. 6. The stage coupler is glued to the booster body tube, with the adapter for the upper stage engine mounting positioned forward to allow the stage coupler to fit into the upper stage, while the tube adapter in the booster is positioned to the rear.

Fig. 6



The most satisfactory method of mounting engines in rockets with large diameter tubes involves positioning the upper stage engine holder tube to project 1/4" rearward from the end of the main body and positioning the engine block so the engine projects 1/4" rearward from the end of the engine holder tube (see fig. 7). This allows the engine to be held in place in its mounting by wrapping a layer of masking tape tightly around the end of the tube and the engine as in fig. 7B. The engine mounting in the booster must be built to leave space for this engine mounting (see fig. 7C).

Fig. 7A

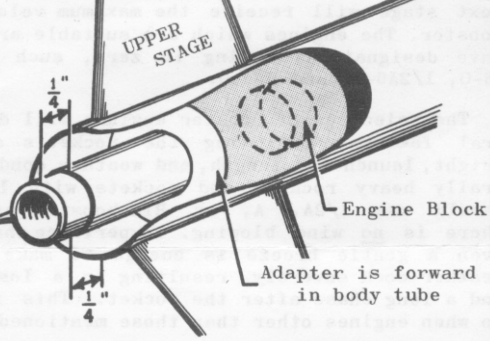


Fig. 7B

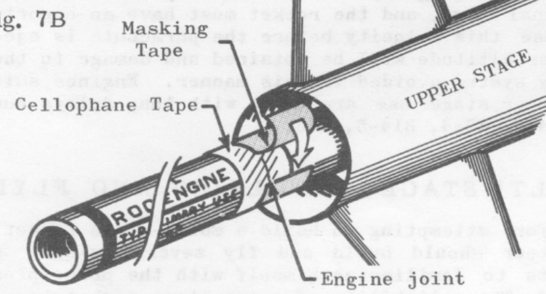
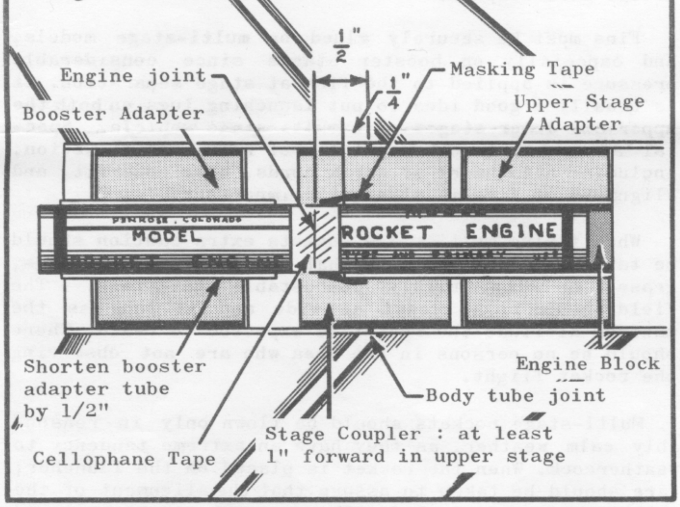
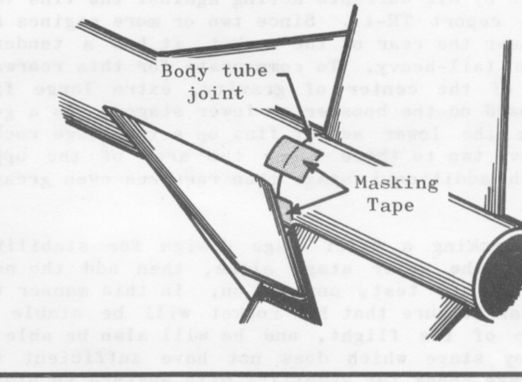


Fig. 7C



Normal procedures call for taping the engines together with cellophane tape before mounting in the rocket. By doing this a better coupling is achieved. Figure 8 illustrates a slightly different method, recommended for use with Series I and Series III boosters only. Applying tape to the outside of the rocket is easier than taping the engines, but is also poor aerodynamic practice.

Fig. 8



With any coupling system, certain rules must be carefully followed. Engines must be held in their respective stages securely. Engine blocks must be strongly glued. Engines may be secured in their body tubes by (1) wrapping tape around the middle of the engine until it makes a very tight friction fit in the body as in fig. 9A, (2) taping the end of the engine to the engine holder tube as in fig. 9B, or (3) by a combination of wrapping the engine with tape and properly positioning engine blocks as in fig. 9C.

Fig. 9A

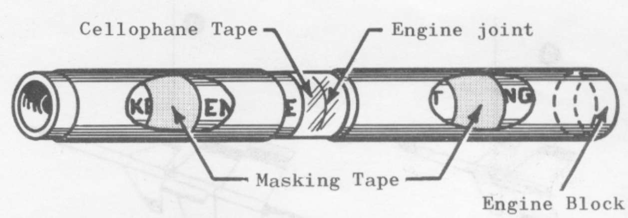


Fig. 9B

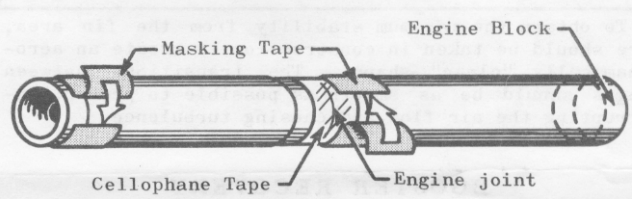
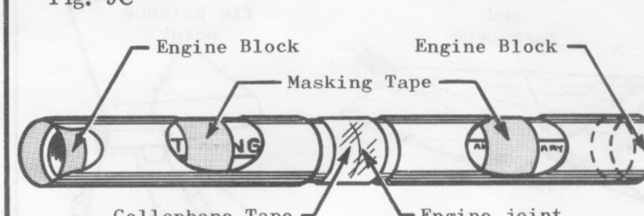


Fig. 9C



When the forward wall of propellant in the booster ruptures and hot gases blow forward, the joint between the engines is pressurized. If the rocket has been constructed with proper care and the engines mounted carefully, the tape that holds the stages together will break, allowing the stages to separate, but not until the upper stage has ignited. If proper care is not exercised, almost anything can happen.

STABILITY

Multi-stage rockets, like single stage rockets, are stabilized by air currents acting against the fins (see technical report TR-1). Since two or more engines are mounted near the rear of the rocket, it has a tendency to become tail-heavy. To compensate for this rearward movement of the center of gravity, extra large fins must be used on the booster or lower stages. As a general rule the lower set of fins on a two stage rocket should have two to three times the area of the upper set. Each additional stage then requires even greater fin area.

When checking a multi-stage design for stability, test first the upper stage alone, then add the next lower stage and test, and so on. In this manner the builder can be sure that his rocket will be stable in each step of its flight, and he will also be able to locate any stage which does not have sufficient fin area. Always check for stability with engines in place.

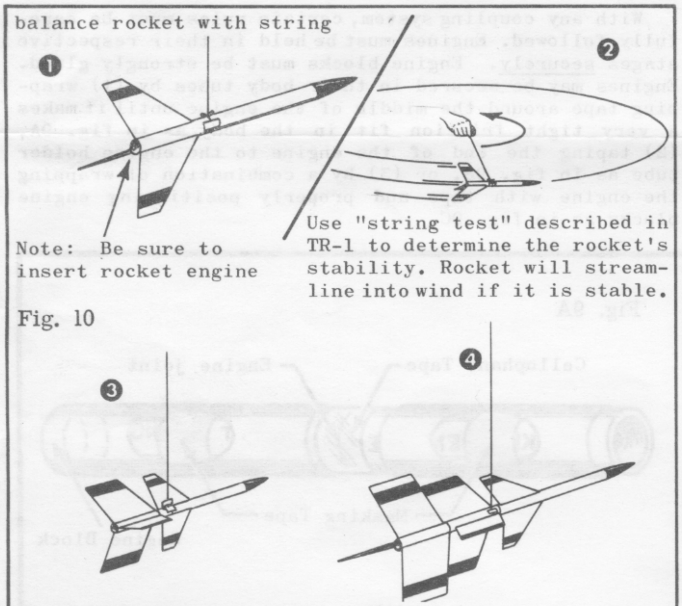


Fig. 10

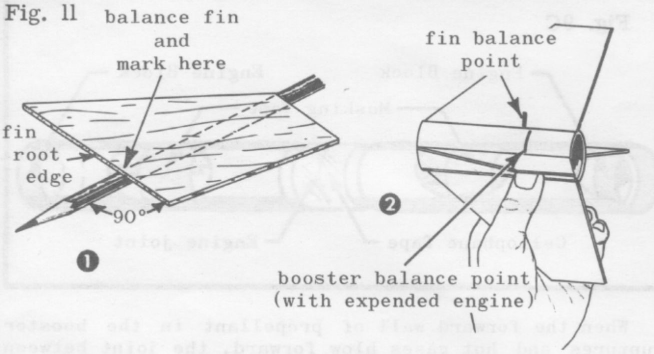
Repeat the above proceedure with each additional booster section. Be sure to insert a rocket engine in each stage.

To obtain the maximum stability from the fin area, care should be taken in construction to create an aerodynamically "clean" shape. The transitions between stages should be as smooth as possible to prevent interrupting the air flow and causing turbulence.

BOOSTER RECOVERY

Most lower stages are designed so that they are unstable after separation. This is because the booster alone is "nose-light," since its center of gravity is fairly close to the stage's rear. The booster should be built so that the center of the area of the fin (its balance point) matches or is up to 1/4" ahead of the booster's balance point with an expended engine casing in place. Thus boosters will require no parachute or streamer, but will normally tumble, flutter or glide back to the ground. If the booster is to be used again, it should be painted an especially bright color, as it does not have a parachute or streamer to aid in spotting it once it is on the ground.

Fig. 11



1. Before assembling the booster, balance one of the fins. Mark the balance point at the fin's root edge.
2. Balance the assembled booster with an <u>expended</u> engine casing in place. The fin balance point must either match or be slightly forward of the booster balance point.

TYPES OF ENGINES

Lower and intermediate stages always use engines which have no delay and tracking charge, and no parachute ejection charge. There is no delay so that the next stage will receive the maximum velocity from its booster. The engines which are suitable are those which have designations ending in zero, such as the A8-0, B6-0, 1/2A6-0S and B14-0.

The selection of booster engines will depend on several factors, including the rocket's stability and weight, launch rod length, and weather conditions. Generally heavy rockets and rockets with large fin area should use 1/2A, A, or B14 booster engines unless there is <u>no</u> wind blowing. Experience has shown that even a gentle breeze is enough to make these models weather-cock severely, resulting in a loss of altitude and a long chase after the rocket. This is especially so when engines other than those mentioned are used.

In the upper stage an engine with a delay and tracking charge and parachute ejection charge is used. As a general rule the longest possible delay should be used, as multi-staging imparts considerably more velocity to the final stage, and the rocket must have an opportunity to lose this velocity before the parachute is ejected. Greater altitude will be obtained and damage to the recovery system avoided in this manner. Engines suitable for upper stage use are those with long delays such as the B4-6, A5-4, B14-5, etc.

MULTI-STAGE -- BUILDING AND FLYING

Before attempting to build a multi-stage rocket, the rocketeer should build and fly several single stage rockets to familiarize himself with the principles involved. The reliability of a two stage rocket is always less than a single stage rocket, and as more stages are added the reliability drops even farther. Hence more building and flying skill is required as the rockets become more complex.

Fins must be securely glued on multi-stage models, and especially on booster stages since considerable pressure is applied to the fins at stage separation. It is usually a good idea to put launching lugs on both the upper and lower stages of a multi-stage vehicle. Special attention to other details of rocket construction, including attachment of shock cords, nose cone fit, and alignment of fins is also quite important.

When flying multi-stage rockets extra caution should be taken to select a field that is free of dried weeds, grass, or other highly combustable materials. The field should be at least as wide and as long as the maximum altitude the rocket is expected to reach. There should be no persons in the area who are not observing the rocket flight.

Multi-stage rockets should be flown only in reasonably calm weather, as they have an extreme tendency to weathercock. When the rocket is placed on the launcher, care should be taken to assure that the alignment of the stages is not disturbed. Observers should be assigned to follow each individual stage to prevent the loss of part of the rocket.

General safety precautions such as adequate recovery systems, not launching when planes are overhead, and others which are normally taken with single stage rockets should also be taken with multi-stage rockets. Attention to safety rules makes rocketry activities considerably more enjoyable and educational.