The Artificial Incubator

by Kerry Hoffman
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I had just asked an old-time aviculturist, Birdie Whitelaw, about his remarkable success with artificial incubation. It seemed that every fertile egg he set in his incubator hatched into a healthy, vigorous chick.

Birdie opened his toothless mouth in a sly smile and said, "I just take an egg, heat it up for a spell, and out comes a little birdie."

If I had only known that fifteen years ago, I may not have wasted all that time studying incubation. I must remember, though, that artificial incubation can be described as being nine parts science and one part magic and though I have met a few people, like Birdie, who I consider masters in the art of artificial incubation (and I revere them as alchemists of the highest order), you don't have to know magic to hatch an egg in an incubator. Incubation is still nine parts science and with a little knowledge of how an incubator works, how an egg develops and hatches, and a bit of practical common sense, anyone can develop satisfactory artificial incubation techniques.

The Egg

In mammals, when a female ovulates, a tiny follicle ruptures on the ovary releasing a one-celled gamete called an egg cell. If fertilized, it attaches itself to the lining of the female's uterus and draws its nourishment from the systemic nutrients of the female. Bird ovulation is very different. When an ovarian follicle ruptures in a hen, an entire egg yolk is released. On the surface of the yolk is a tiny gametic spot called the germinal disk, blastodisk, or germ spot. This light-colored dot is visible on all egg yolks, fertile or infertile.

The yolk is then captured by the infundibulum of the hen's oviduct. Here is where fertilization takes place; the sperm cell unites with the gametic portion of the egg on the germ spot. Quickly, the vitelline membrane is laid down around the yolk, wrapping the developing zygote in the first of several protective coverings. As the egg passes through the hen's oviduct the albumen, or egg white, is wrapped around the yolk and this is all covered by the inner shell membrane, the outer shell membrane and the egg shell. Penetrating the shell are millions of tiny pores. These pores allow oxygen to enter the egg and carbon dioxide and other wastes to exit the egg. Covering the shell is a waxy cuticle, or "bloom." This "bloom" prevents a too rapid loss by evaporation of moisture from the egg.

Birdie Whitelaw, backwoods aviculturist, inventor, handyman and general wizard.

Finally the egg is laid. The egg-laying process takes about twenty-four hours from release of the yolk from the ovary to depositing the egg in the nest. During that twenty-four hour period the embryo is exposed to the body heat of the hen and the zygote begins to develop.

When the egg is laid, no longer kept warm by the hen's body heat, it cools to room temperature. This gradual cooling arrests the development of the embryo at a primitive, microscopic stage and causes the egg contents to contract. As they cool and contract, the inner shell membrane pulls away from the outer shell membrane, forming the air cell.

When the egg is reheated during incubation the embryo develops quickly. In the first few days a heart forms and blood vessels surround the yolk, pulling nutrients from the yolk and albumen and delivering them to the embryo. The eyes begin to develop, limb buds are formed and the chick begins to move on its own. This first one-third of incubation is very important to the developing embryo; extreme variations in temperature and/or humidity or inadequate turning of the egg can cause the death of the chick.

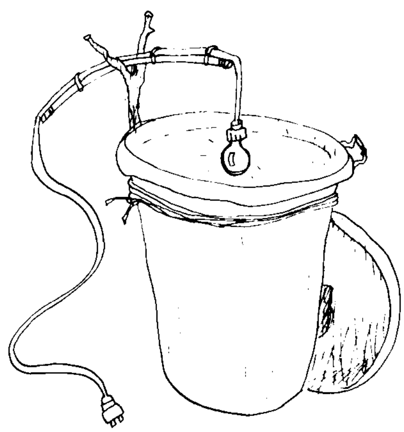
About two-thirds through incubation, the embryo, now a chick, has developed down feathers (if it hatches with down) and is very active in the shell, responding to light, vibration, and loud noises. During the last third of incubation the chick grows to completely fill the shell and positions itself, head under right wing, for the hatch.

The Incubator

There are two main types of incubators; the forced-air incubator and the still-air incubator. The forced-air incubator has a continuously-running fan mounted inside the incubator to keep the warm air circulating around the eggs. Because the still-air machine does not have a fan, the management of it is different than the forced-air incubator. These differences will be pointed out, where appropriate, throughout the rest of this article.

All incubators have at least three parts in common. They are: (1) a cabinet, (2) a heat source, and (3) a source of humidity. Beyond that there are as many variations as there are people with better ideas. I met a man who had perfectly acceptable hatches using a plastic garbage can, a light bulb and a pan of water. At the other end of the spectrum,

Drawing by Debby Clutter, Tucson, Arizona



Birdie's incubator. He has used it for years and has always had nearly perfect hatches. I refuse to try to explain it.

I know a man whose incubator is equipped with two thermostats (in case one fails), an alarm system that will also page him at his house in case there is an accident, spot lights and stereo speakers mounted inside the cabinet. (The lights and sound system are used to stimulate and exercise the developing chick — like teaching calculus to your child before it is born.) And this man has good hatches, too. As you develop incubation skills and begin to feel comfortable with the basics, your machine may undergo some modifications, but my advice to the beginner is to buy a machine and follow the manufacturer's recommendations.

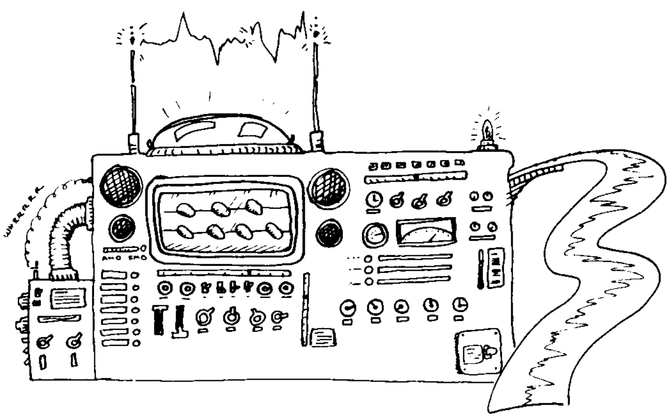
The cabinet is simply the container that traps the heat and humidity around the incubating eggs. It can be made of wood or plastic but should be insulated well enough that your heat source doesn't have to work all the time. There should be at least two adjustable vent openings and a way to read the temperature and humidity without opening the machine. The heat source can be a light bulb, but a radiant heat element is preferable as too much light in the incubator may damage the developing embryo. Humidity is usually supplied by means of a pan of water in the bottom of the machine. The humidity can be increased or decreased by changing the surface area of the water to encourage or discourage evaporation. Large, shallow pans provide the greatest surface area of water and, therefore, the highest humidity. Smaller, deeper pans decrease the surface area of the water and, as a result, the humidity. If large, shallow pans are not raising the humidity in your machine to the desired level, pieces of sponge in the water pans will increase the evaporative surface area of the water and raise the humidity level.

Beyond the three basics, there are a few devices that make artificial incubation easier and more reliable. The thermostat, as its name implies, maintains a steady temperature by turning on and off the heat source. There are several types of thermostats. One style which has been around for years and is still widely used is the wafer thermostat. This fairly reliable device is simply a pair of wafers, each consisting of two round pieces of metal welded together with ether gas in between. As the temperature in the incubator rises, the ether gas in the wafers expands, forcing the metal disks apart. The outer wafer then makes contact with a button switch which turns the heat off. As the temperature drops, the gas contracts, the outer wafer moves away from the switch, opening the circuit and turning the heat back on. Wafer thermostats will wear out after extended use, but they are relatively inexpensive so it's a good idea to have a few extras on hand. When they wear out they become terribly inaccurate quickly and should be replaced immediately as they can no longer be considered trustworthy.

Another type of thermostat is the electronic unit which responds to temperature electronically and controls the heating element by means of a transistor or a microchip. I have heard some negative comments about these units. They are very sensitive to adjustment and great care must be used when fine-tuning the machine to the desired 1/4 °F as a slight slip will change the temperature by as much as two degrees. Despite this minor irritation I have found them to be dependable, reliable and extremely accurate.

The mercury switch thermostat is a small thermometer attached to a switch. As the temperature in the incubator increases, the mercury in the thermostat rises until it makes contact with the upper circuit, turning the heat off. As the temperature drops, the mercury falls and makes contact with the lower circuit, turning on the heat. The major disadvantages to the mercury switch thermostats are that they are made of glass and very fragile, they are relatively expensive to replace and they cannot be

Drawing by Debby Clutter, Tucson, Arizona



An incubator used by another friend of mine with stereo speakers, spotlights, constant printed temperature and humidity printout and several alarm systems. He says all incubators will look like this in the near future. I doubt it.

adjusted. For each 1/4 °F variation in temperature you desire, you must have a different mercury thermostat. In my experience, however, they are well worth the trouble as they are absolutely accurate and extremely reliable.

Along with a quality thermostat, an accurate thermometer is essential to an artificial incubation program. If a thermometer is off by as little as 1/2 °F over the incubation period, the chances of a successful hatch are greatly diminished. Before every artificial incubation season your thermometers should be tested against a clinical thermometer (the drug store fever thermometer). Simply warm a pan of water and immerse the fever thermometer and your incubator thermometer. After a minute or so they should read the same temperature. If they don't, you need a new incubator thermometer. Sometimes the mercury column will split and separate in two. The mercury will reunite if the thermometer is frozen at a temperature low enough to draw all the mercury down into the bulb, but I recommend you dispose of the thermometer and buy a new one.

In forced-air incubators the air should be about the same temperature everywhere in the machine so the temperature can be taken almost anywhere, but in a still-air machine the temperature will vary greatly depending on how close the thermometer is to the heat source. Because developing embryos float to the top of the egg, the thermometer in a still-air machine must measure the temperature at a level equal with the top of the incubating eggs.

Automatic egg turners come in a variety of styles, too. In some machines the eggs are placed in a metal grid. A small motor moves the grid, rolling the eggs back and forth at regular intervals. In some machines the eggs are set in trays which are rotated 45 degrees either side of the horizontal, turning the eggs a total of 90 degrees at regular intervals. In other machines the eggs are set in trays and the entire cabinet is rotated 45 degrees either side of horizontal.

No matter which system you use it is essential that the eggs fit snugly, but not too tightly, in the grid or tray so they won't roll too quickly and break. Extreme care should be taken when setting very small or very large eggs to avoid breakage. When using the grid system, which pushes the eggs to roll them, it is preferable to set the grid bar just below the center of the egg. This gives a slight upward push on the egg and is less likely to break the egg. In setting odd size eggs in a tray I have had success using a light gauge wire to divide the tray into various widths to accommodate a variety of egg sizes. However you decide to modify your trays, the primary concern is to hold the eggs stationary while allowing maximum ventilation around the egg shell (don't surround the egg in tissue, sponge or any other solid barrier that could impede air circulation around the egg).

All systems work well, the important thing is to turn the eggs regularly. The developing embryo floats to the top of the egg, remember, and if the egg is not turned the embryo will stick to the inner surface of the shell, inhibiting proper development and virtually destroying any chance of a proper hatch. An egg cannot be turned too often; a chicken was recorded turning her egg over 1,000 times in a twenty-four hour period. Don't attempt that. Three times or more a day is sufficient.

The wet-bulb thermometer, or hygrometer, is equally important and consists of a thermometer, a water reservoir, and a wick that connects the two. The developing embryo loses water through the shell as a by-product of metabolic growth, but a rapid water loss will dehydrate and kill the chick; a certain amount of water vapor in the incubator will prevent this rapid loss of fluid.

The hygrometer measures the temperature of the air as a result of evaporation. Accurate measurements from the hygrometer are dependent on the movement of air across the wet bulb of the thermometer and for this reason the hygrometer will only work in a forced-air incubator.

In order to keep the bulb of the hygrometer's thermometer wet, one end of a hollow wick covers the bulb and the other end of the wick is immersed in water. Through the capillary action of the wick, the bulb of the thermometer stays wet. The water evaporating from the bulb cools the mercury in the thermometer, giving a lower temperature reading than the air temperature thermometer. By means of a complicated formula the relative humidity can be calculated from these numbers. With an air temperature of 100 °F, for instance, a wet-bulb reading of 87 °F will reflect a relative humidity of 60% (see table 1).

TABLE I.

Wet Bulb Reading (°F)	Relative Humidity (%)	
	At 99°	At 100°
90	70	68
89	67	65
88	65	63
87	62	60
86	59	57
85	56	54
84	53	51
83	51	48
82	48	46
81	45	43
80	43	41

Showing relationship between wet bulb reading and relative humidity at two incubator temperatures.

The hygrometer requires little care. At the beginning of the incubation season, remove the wick and test the thermometer against a clinical thermometer in the same way that you checked the air temperature thermometer. This is a good time to replace the wick. I use a length of tennis shoe lace cut to the length I need. If distilled water is used in the hygrometer water reservoir the wick will last longer and the hygrometer will give a more accurate reading. There are fewer sediments in distilled water.

These sediments collect as a hard crust on the wick around the mercury bulb of the hygrometer and prevent evaporation. When a wick begins to get crusty, it should be replaced; simply cut another length of tennis shoe lace and replace the old wick. Make sure there is always water in the reservoir and the hygrometer should be trouble free.

Before the first egg of the year, your machine needs a thorough cleaning and check-up. Use a liquid disinfectant and scrub out the machine and all the equipment in the incubator room, check your thermometers, start up your machines, and set the thermostats. Check automatic egg turners, replace the wick on the hygrometer, try to maintain the desired temperature and humidity levels and oil the motors that require lubrication.

With your incubator running at the proper temperature and humidity, you should fumigate the machine. Formaldehyde gas is often used and can be produced by setting a small bowl in the bottom of the incubator. In this bowl combine 8 cc of Formalin liquid and 8 cc of ammonium hydroxide. Measure 16 grams of potassium permangenate and add it to the liquid, shut the doors of the incubator and *leave the room immediately!* Please be careful to do this with great care as there is an immediate and violent reaction. Allow the machine to run for a few hours with this fumigant and then exhaust the machine and the incubator room.

Putting It All Together

Now that we know how an egg develops and how an incubator works, let's take an egg through the process of artificial incubation from its discovery in the nest through hatching.

When Birdie Whitelaw finds an egg that he thinks should go in his incubator, he puts it somewhere he hopes he will remember later or sometimes he puts the egg in the pocket of his great, baggy bib overalls. Either method is acceptable among sorcerers, but we mortals should handle eggs with extreme care and respect. The egg should be handled with gloves at all times, if possible, to avoid contamination from the oils on your hands. These natural oils can clog up the pores of the egg shell — the embryo's only means of getting oxygen.

The egg is then moved to the incubator room for its initial candling. If an egg is jarred excessively it may develop a floating air cell. This floating air cell can be detected when the egg is first candled; the air cell moves around freely in the egg indicating that the inner and outer shell membranes have separated. The chances that an egg in that condition will hatch are slim at best. At this initial candling, you should also check for blood rings. These appear as a dark ring around or circle on the yolk and indicate an early dead embryo. This means that the embryo started to develop, but died before developing very far. If you are seeing a lot of these blood rings, and your incubator is operating at the right temperature (not too hot), then perhaps your birds are not completely in condition. Maybe it's early in the season or at the end of the season and the birds are either going out or not quite in breeding condition. You should also reevaluate your diets including the vitamin supplements. An improper diet will cause a high incidence of these early dead embryos. When eggs with blood rings are discovered, they should be discarded immediately, as the only thing that will grow in these eggs is bacteria.

In large hatchery operations the eggs are washed before they are set in the incubator. This is not always a good idea for the private aviculturist with a small incubator. The major benefit of washing eggs is that it cuts down on the chances that bacteria will invade your incubator. The major disadvantage of washing eggs is that you can destroy the integrity of the shell by clogging the pores. You should never scrub an egg with anything abrasive, as it will destroy the bloom and cause severe damage to the shell. Personally, I never wash an egg unless it's extremely dirty and then only with great care and respect for the shell, which should be considered a major part of a dynamic organ system of the developing embryo.

A possible compromise to the problem is using an egg dip. A quaternary ammonia solution is commonly used and is readily available in the form of a commercial egg dip from most agricultural supply houses and most feed stores. Allow the egg to cool and then dip it in a warm (120°) solution carefully following the manufacturer's directions. It is important that the dip be warmer than the egg. If a warm egg is dipped in a cool solution, the egg contents contract, pulling the dirt on the shell and other bacteria into the egg which is the opposite reaction to the one you intended. Always remember, a cool egg in a warm dip.

Eggs that are collected for artificial incubation should be allowed to gradually cool and, if they are to be stored for later incubation, kept at 60-65°F at 70-75% humidity. Temperatures above 70°F may initiate embryonic development and humidities below 70% will dessicate the egg. Humidities above 75% may encourage the growth of mold. When storing eggs, a plastic egg flat is the best substrate and the eggs should be stored with the large end up, tilted at about a 20 degree angle from vertical. Moving eggs every day to 20 degrees the other side of vertical will keep the yolk mobile and will prevent the embryo from sticking to the shell. Eggs can be safely stored in this way for five to six days without jeopardizing hatchability. Storing eggs for fourteen days or longer effectively destroys the chances of a successful hatch.

Now set the egg in the incubator, being careful to position it carefully to minimize the risk of breakage. After a week you should candle the egg again. At this stage it will be easy to see if an egg is fertile or not and if the embryo is developing. You should see a network of blood vessels around the yolk and a pumping heart. The very dark spot on the yolk is the eye spot. If the egg is infertile there will be no blood or eye spot; it will look the same as when it was first candled. This is also a good time to look for blood rings again. Clear eggs and eggs showing dark blood rings should be discarded to avoid contamination of the other eggs.

Many automatic egg turners are set to turn the eggs once every hour round the clock. If you don't have an automatic egg turner, you must turn the eggs by hand, but not once every hour. Three times a day is sufficient, but an absolute minimum. The eggs must be turned three or more times a day religiously especially during the first week when egg turning is most beneficial to the embryo. In order to keep track of what you're doing, I recommend using a pencil to mark an X on one side of each egg and an 0 on the other side. Then make sure all the X sides are up at one turning, all the 0 sides at the next turning, and back to the X side at the next. It is beneficial to turn the eggs an odd number of times during the day. This assures that different sides of the egg will be up on successive nights, when the eggs sit for the longest time without being turned. I have never gotten up during the night to turn an egg and I don't think you should, either. It is very important to use only pencil to write on the eggs. Some ball point pen inks and most marker type pen inks will cross the shell barrier and enter the developing egg, possibly harming the embryo.

Now comes the difficult part — the waiting. You can check the temperature and humidity and keep them constant, you can make sure the eggs are being turned, you can cross off the days on the calendar and you can leave the machine alone. The only outcome of interference beyond maintaining the machine will be negative.

Three days before the expected hatch the egg should be candled again for embryo viability. The egg should be dark, full of the developing chick. The chick will move in response to the light of the candler. The egg should now be moved to the hatching area. Many incubators have a separate, stationary hatching tray in the bottom of the machine. This increases the humidity level around the hatching egg because the egg is closer to the water pans and it also holds the egg without turning it; the chick needs to position itself for the hatch and a stationary egg is easier to work in.

Some people prefer a separate hatching machine. This hatcher can be a smaller incubator set at the same temperature but at a higher humidity than your main incubator. Because the membranes surrounding the chick are exposed to the air during hatching, it is important to maintain a higher humidity in the hatcher. This prevents the membranes from drying too rapidly and sticking to the chick. It's a good idea to keep a spray bottle of water in the hatching area (in the machine) as a source of a warm water mist to spray on the eggs as needed during the hatch. Don't drown the chicks, but they must be kept moist.

A piece of cloth as substrate for the hatching eggs will protect the navel of the chick immediately after hatching. This is the spot where the yolk sack enters the chick's body and is very tender right after hatching. Cheese cloth works well, crinoline is very good and some people use a piece of indoor-outdoor carpeting cut to the size of the hatching tray.

The chick should be in position for hatching with its head under its right wing. A small, horn-like structure called the egg tooth has developed on the upper mandible of the chick and is used as a tool by the chick to escape from the shell.

The first stage of hatching occurs a day before the actual hatch and is called the "peeping" stage. The chick has torn through the membranes that separated it from the air cell. At this point the chick's lungs are working mechanically, inhaling and exhaling the air in the air cell. Since there is very little oxygen in

this "dead air" the chick's respiratory needs are still being met by the allantoic membrane — that network of blood vessels surrounding the chick. This dead air is passed over the chick's syrinx, or voice box, and the chick can be heard "peeping" in the shell. If you hold the large end of the egg to your ear you can hear knocking and scratching. This is the sound of the egg tooth against the shell as the chick attempts to break open a hole.

When that hole is made, the chick has entered the "pipping" stage and begins getting its oxygen from its lungs in a normal breathing process. As the lungs take over, the allantoic membrane atrophies; the blood vessels dry up, it is no longer needed. After the initial pip is made the chick will rest for six to 12 hours before continuing the hatch.

The final stage of hatching proceeds rapidly, usually lasting only a few hours. The chick pushes with its feet and systematically turns in the shell, opening a cap in the large end of the egg. During this period the remaining yolk sack is absorbed into the abdomen of the chick, leaving a small umbilicus. This navel can be very tender immediately after hatching but the soft cloth on the bottom of the hatching tray will protect it from aggravation.

Now, from an egg a few weeks ago, we have a real chick and the work begins for the aviculturist — hand raising it. But I only promised to take the egg up to the hatch. The rest is up to you.

I have included a table of common problems in incubation and their possible causes. The greatest periods of chick mortality are the first third and the last third of incubation. During the first few days of incubation the cells of the embryo are differentiating into various body parts. If the majority of your deaths occur in this stage of incubation, look to the management of your breeders for the possible causes. Is your diet adequate? Are you breeding brother to sister or mother to son?

If there are a lot of deaths during the last third of incubation, you should suspect your artificial incubation techniques (see table 2 for common problems and possible causes).

For more information contact your local Department of Agriculture Extension agent or write to the nearest University Agricultural extension service and ask for a listing of their bulletins on birds. Most of the information will be about chickens, but in many general ways a bird is a bird is a bird and that information can be extrapolated to solve many of your management problems.

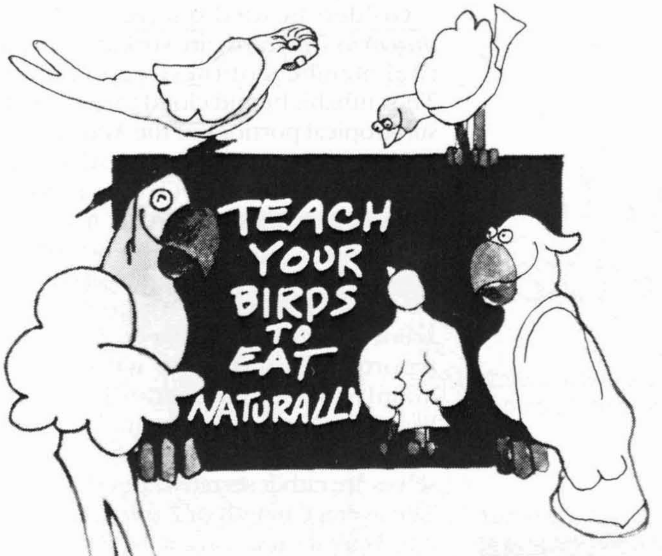
TABLE II.

1) Blood Ring	Incubator temp. too high or too low Breeders not in condition Eggs too old when set
2) Dead Embryos (first two weeks)	Incubator temp. too high or too low Not enough ventilation Eggs not cooled before setting Breeder diet inadequate
3) Late hatch	Incubator temp. too low Incubator humidity too low Hatching temp. too low
4) Early hatch	Incubator temp. too high Incubator humidity too high
5) Chick dead before pipping	Hatcher temp. too high Hatcher humidity too high Poor ventilation in hatcher Breeder diet inadequate
6) Chick dead after pipping	Hatcher temp. too high or too low Incubator temp. too high or too low Hatcher ventilation inadequate
7) Chicks hatch large and "soft"	Incubation humidity too high
8) Chicks hatch small and "thin"	Incubator humidity too low Thin shelled egg Eggs produced in hot weather
9) Crippled chicks a) Cross-beak b) Crooked toes c) Wry neck d) Chicks cannot stand	Variation in temp. a) Hereditary b) Improper temp. c) Nobody knows d) Improper temp. in incubator Incubator humidity too high Breeder diet inadequate
10) Mushy chicks, unhealed navels, wet and smelly	Unsanitary incubator and/or hatcher
11) Bloody navels	Temp. too high
12) Unhealed, dry navels	Hatcher humidity too high Hatcher temp. too low
13) Malpositions	Continuous light in incubator
14) Chicks hold their eyes closed	Loose down in hatcher Hatcher temp. too high Hatcher humidity too low

Trouble-shooting your incubation program.

The incubator should be considered simply a tool in the avicultural program and can be as easy or as difficult to use as any other tool. The incubator can be as simple as a cardboard box with a light bulb and a water pan or as complicated as the new self-regulating, automatic turning models currently available. Like any other tool, the trick is to use it appropriately. I can still hear Mr. Anderson, my eighth grade shop teacher, saying, "Hoffman, how many times do I have to tell you, 'The right tool for the right job'," as I tried to pound in a nail with the handle of a screwdriver. In the same way that a screwdriver won't do the job of a hammer, an incubator may be an inappropriate tool if other techniques are available. Egg fostering, for instance, is a very effective tool.

Remember, anything that hatches in the incubator will have to be hand raised, so in most cases artificial incubation should be considered only when your other options have been exhausted. But, because there are times of last resort, an incubator remains an essential tool; a tool that the serious aviculturist cannot afford to be without. ●



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