History of MIG (and TIG) Shielding Gas Flow Control

By: Jerry Uttrachi, President WA Technology

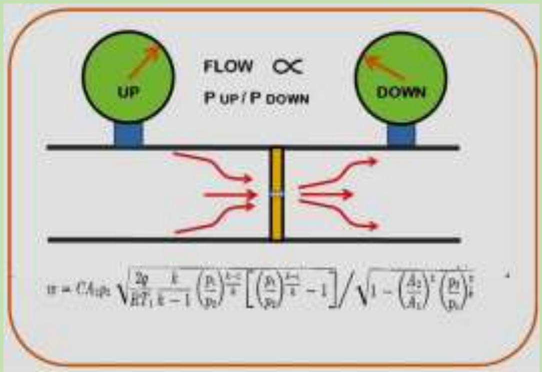
We are often asked questions, including from engineers, requesting more knowledge about MIG (and TIG) shielding gas flow control.

Not surprising as even the American Welding Society 5 Volume Set, of Welding Handbooks with several thousand pages, has little shielding gas flow setting and control information! This "history" will help.

When the first usable MIG system was developed in 1950 by Airco, their patent US # 2,504,868 said one of the key elements was a MIG gun that provided quality shielding. In Claims 8, 9, 11 and 12 they state the shielding must be, *" nonturbulent to exclude air from the arc."* For MIG welding typical Gun gas nozzles are 5/8-inch ID and several published articles show to maintain smooth laminar flow it must be below 50 to 60 CFH. However, in 1950 Short Circuiting MIG welding had not been developed. For sheet metal and out of position welding (*where the first MIG welding with solid wire was used*) wires as small as 0.020-inch diameter were used. Currents over ~75 amps were needed to get stable metal transfer. Typical MIG Gun nozzles for 0.020 through 0.030 wire size is 3/8 inch ID. Where with the typical 5/8 MIG Gun nozzle allowed a max flow of ~55 CFH to avoid excess turbulence flow rate cannot exceed about 30 CFH for 3/8-inch ID nozzles.

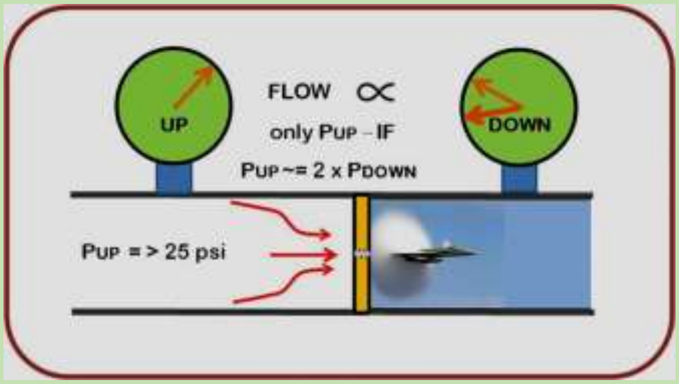
Choked Flow

The two main companies developing MIG welding were Airco and Linde the dominant and largest Industrial Gas Companies at the time. They had R&D engineers specializing in gas flow control as their primary equipment at the time was oxyacetylene welding and cutting apparatus. They understood that at the very low rates required for MIG (and TIG) downstream restrictions could cause preset flow setting to change. They used an interesting phenomenon called "choked flow designs." Understanding how choked flow works will provide knowledge of what controls MIG flow rates. It will help avoid the pitfalls of using devices that eliminate this essential feature when trying to control gas use and avoid gas waste.



As pic right shows, gas flow rate is dependent on the pressure upstream and downstream of a small orifice or adjustable needle valve MIG flow control. Equations are complex BUT the logic is understandable.

However, a unique situation occurs when the velocity in that small orifice or needle valve control reaches the speed of sound. Just like why you see



lightening before you hear thunder, gas flow cannot exceed the speed of sound, which is about 770 mph. It takes special devices like converging diverging nozzles to even exceed that level. Once that velocity is reached, the downstream pressure has NO INFLUENCE on gas flow rate. It's all controlled only by the upstream pressure. For typical gases used in MIG and TIG welding that flow rate is reached when the upstream absolute pressure is over 2.1 times the downstream absolute pressure. Absolute pressure is gauge pressure plus the surrounding air pressure at sea level of 14.7 psi. To determine the approximate pressure needed for regulators controlling flow we can use 15 psi and over 2:1 pressure difference.

In MIG welding there is little pressure drop from where the gas enters a MIG welder or MIG wire feeder to the gun nozzle. It will typically vary from 3 to 7 psi depending on the MIG Gun, its length, how it's bent in use, spatter accumulation in the nozzle and if any Gun gas diffuser holes are blocked by spatter etc. If we use an average of 5 psi, then the absolute pressure will be 5 psi + 15 psi = 20 psia (*the "a" is added to show absolute pressure*.) To have choked flow control and maintain the preset flow required the upstream pressure to be ~2 times the downstream pressure. 2 X 20 psia = 40 psia. To get back to gauge pressure subtract 15 psi from 40 psia = 25 psi. It's no coincidence that *quality flow control regulators* for MIG and TIG welding *all exceed 25 psi!* I started working in Linde welding R&D with ~125 professional when I graduated college in 1964. We mostly sold shielding gas regulators and flow controls that operated at 50 psi. Shown in pic right, it had a square flow tube with silkscreens for various gas flows. Of

interest all hospital flowmeters controlling oxygen operate at 50 psi. Typical human breathing rate at rest is similar to typical MIG flow rates, 30 CFH! So, when providing oxygen to a patent the small hose attached to a face mask or nose clip can bend and twist and still maintain the preset flow!

For piped shielding gas supply, typical pressures are 50 psi, so our "square tube" 50 psi calibrated flowmeter (pic left) was commonly used. These both gave accurate flow readings, and the preset flow was maintained regardless of downstream pressure restrictions inherent in operation.

How Shielding Gas Flow is Set and Measured

There are two types of flow controls used for cylinder supply. Both have a regulator that attaches to the cylinder. The first and a very common type is called a Regulator/Flowgauge. It has two gauges. One is a cylinder contents gauge that displays the pressure in the cylinder. The pressure varies with contents. When full, it typically is 2500 psi for Argon, Argon Oxygen and Argon CO_2 mixtures. As the content is used it will decrease.

The other gauge is calibrated in CFH. Since you now understand choked flow, its operation is simple. There is a very small hole or orifice at the exit of the regulator. It can be separate or is often machined in the outlet fitting. It can be in the range of 0.025 inches. At all practical welding flows the velocity in the orifice is the speed of sound. However, gas density is dependent on pressure, as the regular adjusting screw is turned in the pressure increases. Therefor the gas density increases and for that same velocity of the speed of sound more gas exits! Typical operating pressures for the typical MIG flow rates of 25 to 50 CFH the pressure may vary from 40 to 60 psi. The exact pressure is dependent on the specific model design.

The other common device is called a Regulator/Flowmeter and uses a fixed pressure regulator with a flow tube and float or ball. That type was previously discussed and most common are set at 25 psi, 50 psi and some for CO_2 service 80 psi.

Portable Flowmeter

A discussion of how the flow tube meter works is covered in this product we sell called a Portable Flowmeter (PFM.) It's inexpensive and can be placed vertically at the end of a MIG Gun (or TIG torch) and provide an accurate measure of the gas flow exiting the nozzle. Technically called a Variable Area Flowmeter, it consists of a very accurately tapered tube, with a 'float', which in our devise a round ball. Inside the float (or our ball) is pushed up by the drag force of the shielding gas flow and pulled down by gravity. A higher volumetric flow rate through a given area increases flow speed and drag force, so the float will be pushed upwards. The shape of the tapered tube and the silk-screened flow rate marks define the accuracy of flow readings. Measurements are very repeatable.

Typically, accuracy is quoted at 5% of full scale. We tested the custom product we buy in a large quantities to get readings in CFH. In samples from the bottom, center and top of what we received it was well within the 5% from the 15 to 40 CFH tested.

Pipeline Gas Supply

Controlling shielding gas flow and setting the desired flow rate differs on a pipeline gas supply. At each welder gas flow control drop from a pipeline a regulator is not needed. In a typical liquid supply system, an evaporate takes liquid gases and often blends in a mixer to deliver the desired gas composition. That is often Argon with a smaller percentage of CO_2 or Oxygen. At the end of the gas mixer is a regulator set at a fixed pressure that feeds the pipeline. Typically, that pressure is set at 50 psi.

So, a flowmeter with variable area tube can be attached directly to the 50-psi outlet and the desired volume set with a needle valve adjustment. It can be the same flowmeter that is on the output of a cylinder regular. It's important that the flowmeter be calibrated at the pipeline pressure (pic right.) We have found a majority are NOT! *We see many installations with flowmeters calibrated at 25 psi, which will read about 28% low!* So, when reading 35 CFH they are actually flowing 45 CFH! A source of waste. Our Portable Flowmeter (PFM) can be used, and a mark made on the production flowmeter tube with a Sharpie!

For lower volume needs, some distributors are manifolding a number of cylinders on a fabricated pallet arrangement. The cylinders are piped together as the pallet right The output is then connected to the fabricators pipeline often with a standby 2nd cluster of cylinders. This is often called Mini-Bulk supply, and some have automatic switching to the back-up manifolded cylinders so the empty can be replaced.

A simple flowmeter can be used as the output of the pipeline drop as the cluster output is controlled by a regulator.

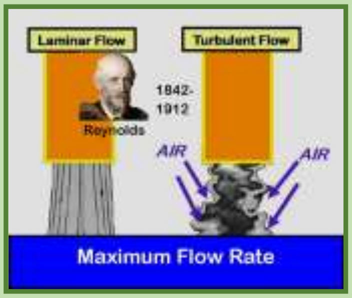
Use of a Fixed Orifice to Control Flow

Since the pipeline pressure is fixed, an inexpensive fixed orifice flow control can be used. Some like this option as it takes flow control away from the welder. However, flow can't be varied for current level, the presence of a drafts etc. Typically, these systems are set for the highest flow need and can waste gas.

Note, although placing an orifice at a welder or wire feeder inlet eliminates needed extra gas purge at the weld start, placing it at the pipeline drop does not.

BUT High Pressure Causes a Problem

Pressures needed to assure "choked flow" or automatic flow compensation regardless of inevitable downstream restrictions cause a problem at weld starts. The pressure at the welder or wire feeder inlet needed to flow the nominal 35 CFH is only ~5 psi. Therefore, when using a 50 psi (*or even the minimum pressure required for "choked flow of 25 psi*) when welding stops, and the gas control solenoid shuts in the welder or feeder. But gas continues to flow in the needle valve or orifice until the pressure in the gas delivery hose quickly equals the higher pressure. The gas delivery hose from gas supply flow control to welder/wire feeder quickly fills with the higher pressure. Using gas laws, the volume of gas is proportional to the pressure. So that extra gas stored at increased pressure "blasts out" of the MIG gun nozzle at every start. We (and others) have measured peak gas flow of over 200 CFH.



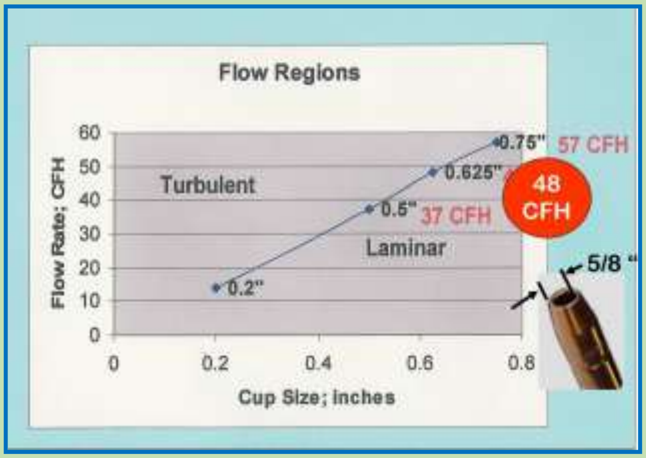
From the Airco MIG patent with 4 claims saying the shielding gas flow must be non-turbulent, that flow surge at the start is mixing moisture laden air into the gas stream. Osborne Reynolds work published in 1890 defined even a worse problem than the audible gas surge. He found there was a specific flow velocity where the transition occurred from smooth Laminar flow to more chaotic Turbulent flow. He also showed that once Turbulent flow occurred, it took time for it to become smooth Laminar flow even after the flow velocity lowered to the Laminar level. Therefore, after each weld start, the high peak flow velocity pulls moisture laden air into the shielding gas stream causing excess spatter and other quality problems.

Linde R&D engineers developed a solution particularly for the low ~20 CFH flow rates being used with the small, 0.020 to 0.030-inch diameter wire. The max flow for the small MIG Gun nozzles used was about 30 CFH to avoid turbulence. They developed an orifice that screwed into the CGA Inlet gas fitting on MIG wire feeders and welders. It would limit peak flow and avoid the over 150 CFH peak they saw was occurring in the starting "gas blast." In fact, it's still sold today with the same 1950's part number, 19X76. (*You can tell the age as it used the part numbering system used in the 1950's and prior.*

So, while the R5007 Regulator Flow control was set at say 20 CFH the 19X76 peak flow control orifice mounted at the welder or Wire feeder gas inlet limited peak flow to about 45 CFH and did not allow it to reach over 100 CFH and have Turbulent flow continue even after the flow rate reduced to 20 CFH for a short time pulling in moisture laden air. Unfortunately, some think it was designed to control the steady state flow- IT WAS NOT.

What Flow Rate Causes Turbulence?

Although little is published about the flow rates causing turbulence in MIG (and TIG) welding many have stated much beyond 50 to 60 CFH causes inferior shielding with the typical 5/8-inch ID Cup or nozzle. Several R&D efforts used a late 1800reds flow imaging device called a Schlieren. One excellent older technical paper used interesting methods to directly define turbulence in shielding gas flow. One was to measure the oxygen near the weld to define what flow created air mixing with the shielding gas stream. Other approaches were also utilized.

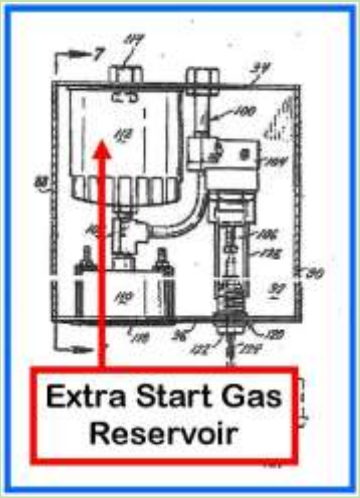


As noted on the pic left, for a small 3/8-inch ID nozzle/cup, turbulent flow starts at ~30 CFH.

Unfortunately, some thought they could just control the steady state flow with an orifice etc at the welder/wire feeder gas inlet. But like any device trying to control flow at that location it provides no extra gas needed to purge air from the MIG Gun or the weld start area. Welders can often see the starting issues created and reject that approach. The next subject deals with that issue.

Need for Some Extra Start Gas Defined in 1982 Patent

Stauffer in US patent 4,341,237 defined the need for extra start gas in his shielding gas waste control device. His device was designed to mount close to the wire feeder gas inlet setting and locking flow settings. He added a rather large starting gas storage volume element (*item 112 in patent figure right)* because his device also used relatively low pressure, less than the 25-psi needed to achieve choked flow. The patent states: *"... air leaks back into the MIG gun and lines when welding is stopped. The air must be quickly purged and replaced with inert gas to produce high quality welds. Also, it is critical to displace the air at the weld zone of the work piece upon initiating the weld."*



The devices flaw of not controlling flow with inevitable varying flow restrictions in operation AND its many internal gas connections (reportedly prone to leak) probably caused it to no longer be sold.

Any Device Controlling Flow at The Welder or Wire Feeder Gas Inlet Causes Lack of Sufficient Starting Gas

Although little is written on the shielding gas waste issue a field engineer for Praxair is quoted in an industrial trade publication stated their findings are the average shop wastes from 3 to 5 times the shielding gas that should be used! Several types of devices have been tried over the years to reduce the know shielding gas waste.

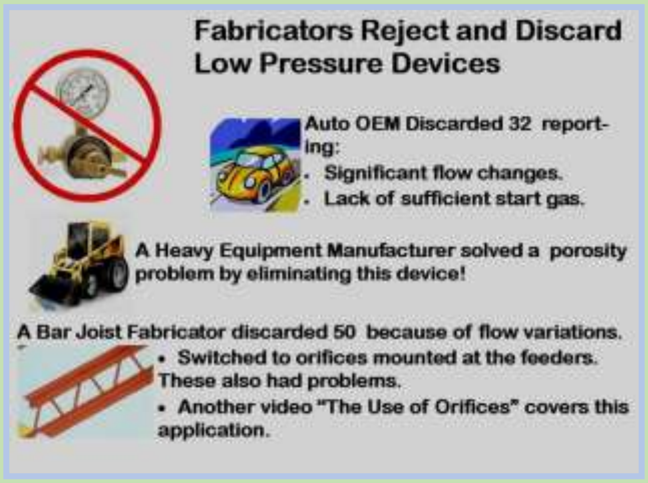
Some maintain "automatic flow compensation" by not using less than 25 psi. The two regulators left are of that type. Some like the 19X76 use simple orifices to set steady state flow and screw into the gas inlet fitting on the wire feeder. I few fabricators have tried to just install a flow control and needle valve at the wire feeder inlet as shown in the pic lower right. Have an interesting observation of a shop that had 100 welders using that method that allowed quantifying the problem it created. It follows.

The shop installed the flow controls at the 100 wire feeders with the objective of reducing gas waste. They were all connected to a 50-psi pipeline and the L-33 flowmeter is calibrated at that pressure, so the flow readings were accurate. In a survey of the shop, found none were set lower than 50 CFH. 25% were set at the max flow reading on the flow tube, 70 CFH. 25% were set where the flow ball was pinned to the top of the flow tube. Tests in our Lab showed with the needle valve turned one half further than the 70 CFH flowed 150 CFH when measured at the MIG Gun! *So why was it set that high?* In another similar application we found welders were trying to compensate with what Stauffer found in 1982- LACK OF SUFFCIENT STARTING GAS TO PURGE AIR! Welders may not even know the reason but saw weld starts improve. Frankly, as many of us have been caught starting to MIG weld without turning on the gas cylinder valve the excess start spatter is instantly seen! Staring without sufficient extra start gas is like starting without gas. It a similar application we were able to reduce the flow rate being controlled with simple orifices at ~50 CFH to ~35 CFH with BETTER STARTS. Increased steady state flow can help start quality to some extent BUT a small, controlled amount of extra start purge gas provides superior starts!

Worse Low Pressure Controlling Flow at Wire Feeder

The worst supposed "gas saver" product mounts at the welder or wire feeder so has the lack of needed extra starting gas to purge air and eliminated "automatic flow control." It also uses low pressure in attempt to save gas! With no change showing on the flow control gauge, when set at 31 CFH we have measured flow from 16 to 37 CFH with typical flow restrictions!

A number of fabricators have relayed their experience with the low-pressure device that mounts on the wire feeder:



This device sells for over $200 and is supposed to reduce gas waste. The four companies shown on left stated why they removed and discarded the device.

Of interest the bar joist fabricator had removed 50, six months before I was called in because of unhappy welders. They had switch to simple orifices mounted at the wire feeders set at about 50 CFH BUT welders wanted more flow. In surveying the shop found one still installed. It was set to the maximum flow on the gauge of 80 CFH! It was obvious the welder was trying to compensate for lack of extra start gas. Working with the fabricator we also removed the orifice at the feeder and were able to improve starts with 35 CFH with a 30+ % gas savings!

BTW there are other low-pressure devices that mount at the gas supply BUT they also have the same issue of not compensating for the inevitable flow restrictions that occur in production (pic right of two.)

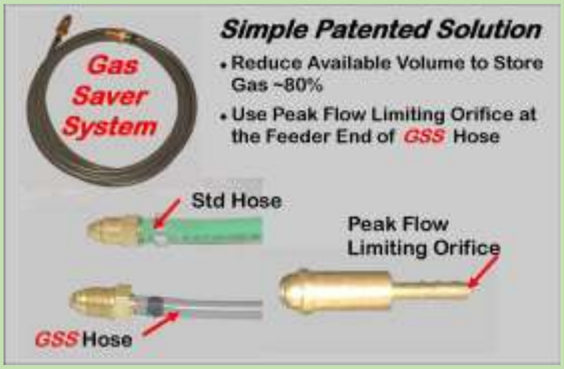
Our Patented Solution to Gas Waste is Inexpensive!

Our patented Gas Saving System solution (*GSS*) has no moving parts and is inexpensive. Most important, welders love the improved starts. They can set the flow at any reasonable flow level with the same quality flow controls they are now using! There are over 15,000 in use typically saving 40 to 50+% of gas usage while improving weld start quality. We also have another patented device that allows locking the flow control knob on most flowmeter flow controls- pic left.

I recall some years ago the VP of a major fabricator said he would load his pockets with quarters before visiting and touring one of their many production plants. He'd toss them on the ground and welders would scurry to pick them up. The plant manager, conducting the tour, would ask, ***"What are you doing?"*** He'd say, ***"That is what you're doing every day - wasting shielding gas!"***

Yep, some fabricators understand and calculate how much shielding gas they are wasting. But a major precept of "Lean Manufacturing" states most waste is invisible. Must work to quantify. Sure fits shielding gas!

Our patented solution is straight forward and simple. It employs a custom extruded small ID, large OD gas delivery hose from flow control at the gas source cylinder of pipeline. That reduces the amount of shielding gas stored when welding stops.

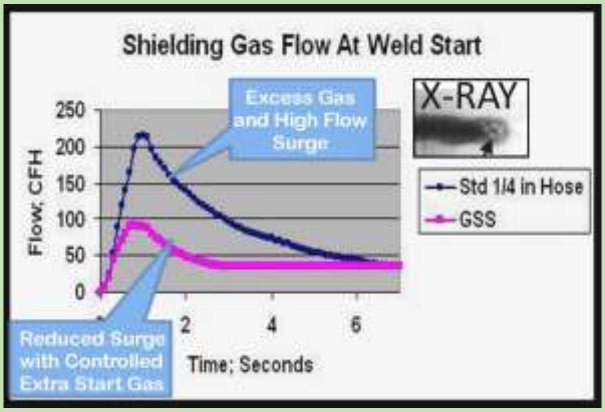


To keep the peak flow from becoming excessively turbulent at each weld start it incorporates a "peak flow limiting" orifice. NOTE, it does NOT control the steady state flow only the peak flow. If welders are foolishly setting very high flows, it will limit flow to under ~90 CFH. But in that situation welders should be trained that anything over about 55 CFH is just pulling air into the shielding gas stream and making weld quality worse. The combination small ID hose and peak flow control orifice typically cut total gas use in half! That assumes leaks are monitored and fixed.

It's simple to install. Just replace the existing gas hose from flow control at gas source to wire feeder or welder. That's it! Set the proper flow and start welding.

Example:

We have hundreds of users and many who have documented their savings results with careful measurement of up to 63%. However, this early customer experience defines not only the 40+% savings they found BUT most important, improved weld start quality.



This was a pipe weld repair application and as soon as the welding engineer and I installed the *GSS* and he was going to measure gas savings the welder said, "This is much better!" NOT in gas savings but weld start!

He was having many rejected repair welds after they were ultrasonically checked. He knew the cause was the high gas surge at the start. He would cut the wire close to the tip and keep the MIG gun high to give time for the audible gas blast to reduce. As can be seen he was facing a 3+ second problem where the flow was turbulent pulling in moisture laden air. After 6 months of use he said he was experiencing very few defects! The start quality sayings were at least as important to reduced gas waste!

Other Information and Links to Technical Reports:

Suggested Range of MIG Flow Settings

MIG Gun Nozzle Size Inside Diameter	Minimum Suggested Flow	Typical Flow Setting	Maximum Suggested Flow
1/2 inch (Typical on Small Welders)	18 CFH	22-27 CFH	~ 40 CFH
5/8 inch (Most Industrial Welders)	22 CFH	30-35 CFH	~ 55 CFH
3/4 inch (For Large Size Cored Wire)	30 CFH	30-40 CFH	~ 65 CFH

Why Chart Industry Has Over 3000 GSSs installed
http://netwelding.com/Why_Chart_Has_3000_GSSs.pdf

7 Companies Report Improved Starts with GSS as Important as Gas Savings
http://netwelding.com/Start_quality_Improvement.pdf

12 Companies Quantify GSS Gas Savings
http://netwelding.com/Fabricators_GSS_Tests_Results.pdf

How Choked Flow Works and Test Results with Low Pressure Device
http://netwelding.com/Automatic_Flow_Control.htm

What Gas Flow Rate Should Be Used (with Chart)
http://netwelding.com/MIG_Flow_Rate_Chart.pdf

Why the High Cost for Argon Gas (*and why it will get worse*!)
http://netwelding.com/Why_High_Gas_Cost.pdf

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